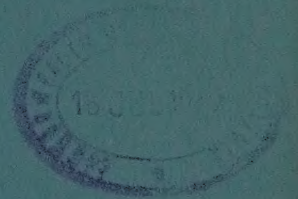
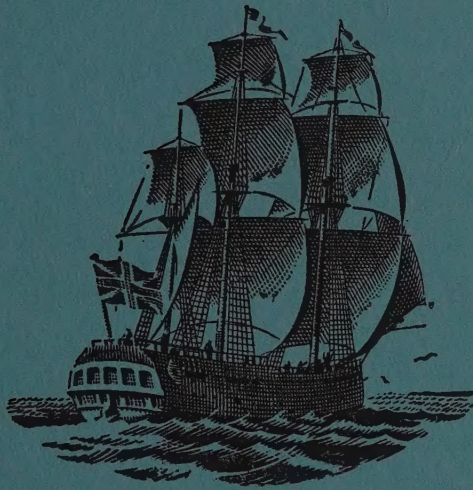


# ENDEAVOUR



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*The drawing on the cover is of the bark Endeavour, which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in 1768 to chart the South Pacific Ocean and observe the transit of Venus*

# ENDEAVOUR

A quarterly review designed to record the  
progress of the sciences in the service  
of mankind

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# On Floras

The recent publication of a new British Flora<sup>1</sup> is an event of major botanical importance. This may sound an extravagant claim, but an up-to-date and comprehensive Flora is an essential tool for the study of the plants of any area—essential not only to systematic botanists, but to ecologists, geneticists, horticulturists, and indeed to all who are concerned in any way with plants. In recent years Britain, almost alone among European countries, has lacked such a tool; the last full-scale British Flora was Hooker's 'Student's Flora,' published over eighty years ago. This lack has seriously hampered the work of British botanists, and since the vegetation of Europe—one may say, of the world—is a single unit, workers in other countries have likewise suffered in varying degrees, and will wholeheartedly welcome the Cambridge publication.

Broadly speaking, early botanical works attempted to deal comprehensively with all known plants, and it was not until the spirit of the Renaissance began to ferment that botanists descended from the clouds of universality and looked with modern eyes at the actual plants growing around them; it was soon after this enlightenment—during the seventeenth century—that Floras as we know them today were first written.

The Greeks, however, provide an exception to every rule. They did not, as far as we know, write formal Floras, but, in the work of Aristotle and especially of Theophrastus in the fourth century B.C., we recognize an attitude to plants and other living things that was not to reappear for nearly two thousand years. Theophrastus went to the plants themselves, rather than to authority, for his botanical knowledge, and made a number of remarkable observations and deductions, including the distinction between monocotyledons and dicotyledons which is still used in classifying the angiosperms. But the early torch lit by the Greeks was not passed on, and at the dawn of the Christian Era we find Dioscorides, a Greek army surgeon, and Pliny, prefect of the Roman fleet, writing monumental and comprehensive works on plants and their medicinal virtues—works of great erudition, but completely lacking the first-hand, observational approach of Theophrastus and his modern followers.

An awakening came in Germany early in the sixteenth century, with the herbals of Brunfels,

Bock, Fuchs, and Cordus—the German 'fathers of botany.' The delightful woodcut illustrations for these volumes were made from nature, not copied from earlier drawings, and many of the descriptions in the text were of plants growing in the central European woods and fields. Although these books were not, strictly speaking, Floras in the modern sense—for most of them included species from other parts of the world, and their emphasis, as the name 'herbal' suggests, was medicinal rather than purely botanical—their excellence set a standard that was to influence all future botanical publications, including the Floras that were soon to be written.

It is difficult to point to a specific work as the first true Flora. During the second half of the sixteenth century, several books appeared recording and describing the plants seen during a journey in a particular country—for example, L'Écluse's on Spain (1576) and on Austria-Hungary (1583), and Alpino's on Egypt (1592)—which can be regarded as the immediate forerunners of the true Floras of the next century. One of the earliest and humblest of these was published in England in 1632, and we can conveniently take it as a starting point for tracing the history of Floras in Britain—a history roughly paralleled in other European countries.

This publication of 1632 was not even a separate volume. It was a mere enumeration by Thomas Johnson of the plants recorded as growing on Hampstead Heath, near London; it appeared modestly as an appendix to the same author's *Descriptio Itineris . . . in Agrum Cantianum*, but it was the first British local Flora, and the volume containing it is one of the most coveted of all British botanical books. Unfortunately, most libraries must mourn its absence, as the *Descriptio* and Johnson's other volume on his Kentish journeys (the *Iter* of 1629) are among the rarest books in the world, only two copies being known of the *Iter* and eight of the *Descriptio*. Johnson was a remarkable man who, by his own labours, bridged the gulf between the medical herbalists and the Flora-writers who studied plants for their own sake. He practised as an apothecary at Snow Hill in London, and edited a magnificent edition of Gerard's 'Herbal,' but before he died in 1644, fighting for his King, he had produced, in his *Mercurius Botanicus*, what was virtually the first Flora of Britain as a whole. The *Mercurius*, though primarily a

<sup>1</sup> *Flora of the British Isles*, by A. R. Clapham, T. G. Tutin, and E. F. Warburg. Pp. li + 1591. Cambridge University Press, London. 1952. 50s. net.



record of botanical tours in England and Wales, lists all the British plants (nearly 700) at that time known to Johnson, and was intended as a prelude to a full-scale Flora which he unhappily did not live to publish.

Once Johnson had pointed the way, there was no lack of followers. After two rather slight attempts at British Floras (How's *Phytologia*, 1650, and Merrett's *Pinax*, 1666), came the first really great—and still, perhaps, the greatest—name in British botany: John Ray of Trinity College, Cambridge. His Floras of Cambridge (1660) and, later, of Britain (1690) were beyond measure superior to any previous writings on British plants, and form the twin foundation-stones on which all subsequent work has been erected. A full record of his life and labours can be found in Raven's 'John Ray: Naturalist,' first published in 1942.

Both Johnson and Ray wrote accounts of the plants of a small, limited area, as well as of Britain as a whole, and these two types of Flora—the local and the general—have ever since continued to appear, influencing and supplementing one another. Local Floras have been written largely by amateur botanists, and Britain, always rich in amateur effort, has almost certainly a better record than any other country in the production of such Floras.

Ray's British Flora of 1690, the *Synopsis Methodica Stirpium Britannicarum*, remained the indispensable standard work for British botanists for the next seventy years—until, in fact, the all-conquering system of Linnæus engulfed the British Isles, and a new Linnæan Flora was inevitably called for. The first worthy response came from William Hudson, for some time *Praefectus* at the Chelsea Physic Garden, London, whose *Flora Anglica* (1762) immediately ousted Ray's *Synopsis* as the standard account of British plants. The Linnæan ascendancy lasted until the third decade of the nineteenth century, and gave rise to a number of successors to Hudson's Flora, of which Sir James Smith's 'English Botany' (1790–1814) was the most outstanding. The 2592 colour plates by James Sowerby make it much prized even today.

When the Linnæan system at last capitulated to the so-called natural system, new Floras quickly appeared reflecting the change, and incorporating the ever-growing mass of new information on the classification and distribution of British plants. It was now that the period just brought to a close by the new Cambridge Flora may be said to have begun—the period of the two Hookers (father and son), of Bentham, and of Babington, whose various Floras, in various guises and editions, have been

used for the last hundred years. Magnificently well they have served; few will superannuate their 'Bentham and Hooker' to the top shelf of the bookcase without 'the passing tribute of a sigh.'

However, as has already been emphasized, a modern treatment of British plants was much overdue, and we can say without hesitation that the authors and publishers of the new Flora have not disappointed our long-deferred hopes. We have referred to it as the 'Cambridge' Flora and so, no doubt, it will rightly come to be called. Inspired by Sir Arthur Tansley, published by the Cambridge University Press, and written by Professor A. R. Clapham, Professor T. G. Tutin, and Dr E. F. Warburg—three former students of Mr Humphrey Gilbert-Carter, to whom the Flora is fittingly dedicated and who for thirty years was director of the Cambridge Botanic Garden—it carries on the great tradition of Cambridge field botany started by Ray in the seventeenth century and kept alive by the Martyns, Babington, C. E. Moss, A. H. Evans, A. J. Wilmott, and many others during the last 250 years.

In general layout and arrangement the Flora inevitably follows the well-trying model of its predecessors in Britain and other countries. There are excellent keys, and the descriptions of the species are clear and succinct; the great majority of recorded hybrids are described or mentioned. Chromosome numbers, where known, are given, together with Raunkiaer's life-forms. With the aid of the glossary, a keen and intelligent amateur should be able to identify any plant he comes across in his wanderings, including many of the naturalized aliens—the authors have rightly been generous in their inclusion of non-native species. A large number of name-changes from those used in existing British Floras has been made; in many cases this is inevitable, but some botanists may feel that, in certain families, the generic concept adopted by the authors is unduly narrow. Text figures are used with good effect to illustrate points difficult to put into words, but the full value of the Flora will come when the promised complete series of line drawings is available for use with it.

The Cambridge University Press has obviously given much thought to the production of the Flora. It is a triumph to have fitted some 1600 pages into a single volume of easily-read type, and field botanists will appreciate the fact that the cloth covers are proof against moisture.

The new Flora is an outstanding contribution to British botany, worthy to stand beside the *Synopsis* of John Ray. There can be no higher praise.



# Radio-astronomy

M. RYLE and J. A. RATCLIFFE

Analysis of the radio-frequency radiation reaching the Earth from outer space has in recent years proved very informative. It has led, for example, to the discovery of what are called radio stars. These are sources of radiation which on some wavelengths greatly exceeds that of the Sun in intensity, but which do not seem to emit visible radiation. Analysis of solar radiation has thrown new light on the nature of the Sun's atmosphere.

Our knowledge of astronomical bodies is derived almost entirely from observations of the radiations they emit. The most important of these are in the form of electromagnetic waves similar to light waves, and it is possible to study only those which are capable of reaching the Earth through its atmosphere. Figure 1 shows roughly the transparency of the atmosphere on different wavelengths, and it will be seen that there are two atmospheric 'windows,' one in the region of optical wavelengths, and one in the region of short radio wavelengths. The cut-off at the short-wave end of the radio-frequency window is due to absorption by the molecules of air, while that at the long-wave end is produced by the terrestrial ionosphere, which prevents the longer waves from reaching us from outer space, just as it prevents waves from our own transmitters from leaking away into outer space. This article deals with the study of those radiations which reach the Earth from outer space and are transmitted through the radio-frequency window to the surface of the Earth.

## DETECTION OF THE RADIATION

If the radiation is received on a tuned radio receiver, it is found that its amplitude fluctuates rapidly in an irregular manner, and through telephones the resulting signal sounds like a rushing noise. It has characteristics similar to those of the irregular e.m.f. which is produced in all resistances, and which has been widely studied under the name of radio noise. Noise of this kind can be considered as made up of a succession of short impulses arriving at random times, and it was shown by Rayleigh many years ago that white light could be considered as made up of just such a succession of randomly timed impulses. The radio noise which we receive from outer space has a random wave-form which corresponds to the description given in Rayleigh's pulse theory of white light, and has a continuous spectrum which is in many respects similar to that of white light.

The reception and amplification of weak irregular noise in a radio receiver presents a difficult problem, because the Johnson and shot effects<sup>1</sup> introduce similar random noise in the amplifier itself. Under these circumstances, the following considerations show that a substantial gain in sensitivity can be obtained by proper attention to the design. Consider the incident noise to be represented by a random sequence of sharp impulses, each of which sets up a decaying oscillation in the first radio-frequency circuit of band-width  $\Delta f$ . Each of these transients will last for a time of the order of  $1/\Delta f$ , so that, on the average, the number of independent transients which can be produced per second in the first circuit is of the order  $\Delta f$ . Suppose now that the recording apparatus at the output end of the set has a time constant  $t$ , so that it records a running average over a time of the order  $t$ . Then the output represents the average of  $n$  independent input transients, where  $n = t\Delta f$ . This average will consist of a steady component together with a fluctuating component, but, as in the averaging of all random processes, the fluctuations will be reduced in the ratio  $1/\sqrt{n}$ . The fluctuations in the output are hence reduced by a factor  $1/\sqrt{(t\Delta f)}$  compared with the fluctuations in the input. It is this fluctuation in the output which will determine the smallest noise e.m.f. which can be detected over and above the noise e.m.f. of the set itself. To obtain the greatest sensitivity, the band-width  $\Delta f$  and the integrating time  $t$  should therefore be made as great as possible. It has been feasible to use a radio-frequency

<sup>1</sup> The flow of an electric current through a thermionic valve involves the passage of discrete electrons whose arrival at random times causes inevitable fluctuations in the current. These fluctuations produce a noise in telephones attached to an amplifier. This is called the shot effect. The discrete electrons in a resistance are in continual thermal motion and produce random electromotive forces across the resistance. These also in turn produce a noise in the telephones attached to a high-gain amplifier. This is called the Johnson effect.



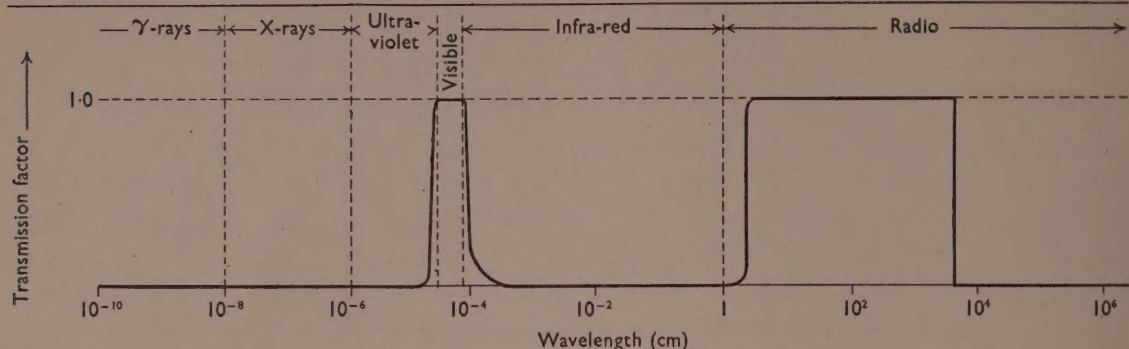


FIGURE 1 — To illustrate the transmission coefficient of the Earth's atmosphere for electromagnetic waves of different lengths.  
(By courtesy of The Physical Society.)

band-width of the order of 1-4 Mc/s (on central frequencies between 40 and 500 Mc/s), and an output integrating time of 0.1-1 sec, so that  $\sqrt{(t\Delta f)}$  is of the order of 1000.

The separation of the received noise from the set noise is usually achieved by switching the amplifier rapidly backwards and forwards between the aerial and a local source of noise. If the noise produced in the local source is not as great as that produced in the aerial, there will be a periodic component of noise in the output. This may be measured directly, or may be used to work a servo-mechanism which adjusts the source until it introduces the same noise as the aerial. When a servo arrangement is used, the local source is generally a saturated diode which is known to produce a noise e.m.f. proportional to its anode current. The servo arrangement alters the filament current, and the anode current is recorded, so as to provide a measure of the noise picked up by the aerial. In this type of automatically adjusted equipment, the amplifier is used merely to equate the noise powers from the aerial and the diode, and its amplification can vary within quite wide limits before the output reading is appreciably affected.

With an automatically recording apparatus it is possible to record and measure noise electromotive forces which are about 3 per cent. of those produced in the set itself. If the e.m.f. to be recorded originates in a matched resistance connected to the input of the amplifier, the sensitivity is such that a change in temperature of the resistance of 1° K would enable the corresponding change in the noise e.m.f. to be recorded and measured.

#### MEASUREMENT OF THE DIRECTION OF ARRIVAL

To find the direction of arrival of the radio-frequency waves it is desirable to use some kind of 'radio telescope.' The simplest type would consist

of a concave mirror with a receiving aerial at its focus, as in an optical reflecting telescope. The accuracy  $\theta$  with which the direction of arrival of waves can be determined with any apparatus of this kind is, however, limited by the ratio between the width  $W$  of the mirror and the wavelength  $\lambda$  of the waves used. The angle  $\theta$ , measured in radians, is of the order  $\lambda/W$ , and is usually spoken of as representing the resolving power of the telescope. It is interesting to compare the resolving powers available with optical telescopes, using light of wavelengths about  $5 \times 10^{-5}$  cm, and radio telescopes, using wavelengths of about 5 m. A comparatively modest optical telescope, with an aperture of 10 cm, would have the same resolving power as a radio telescope with an aperture of 1000 km. It is obvious that, with radio telescopes, we cannot hope to approach the resolving powers which are possible with light. In an attempt, however, to get the best possible resolving power, large mirrors have been constructed, and one of the largest at present in use is that at Manchester. This has an aperture of about 80 m, so that when used on a wavelength of 2 m it has a resolving power of about 1/40 radian, or 1°5.

The limitations which are imposed in radio-astronomy by the finite resolving power are best appreciated by considering what could be observed visually if optical telescopes had a similar resolving power. The Sun would look like a diffuse blur subtending an angle of about 1°5, or about three times its present size. All the stars in the sky would appear of the same size, and their images would overlap to produce a diffuse brightness in the sky. Where there was a particularly bright star, its diffuse image would appear as a bright patch.

Large mirrors are costly and difficult to construct accurately, and there is a physical limitation to their size. It has long been appreciated in



optical astronomy that, in principle, it is not necessary to use the whole of a mirror to achieve the full resolving power, and that only the portions at the edge are required. Michelson made use of this principle in his stellar interferometer, in which he placed two mirrors several metres apart to act like two points on the edge of a very large lens, and arranged that the light from them should form interference fringes in a telescope. He showed how to use measurements of the resulting interference fringes to achieve a much increased resolving power. The same principle has been applied to radio-astronomy.

The two mirrors are replaced by two aerial arrays, separated by as great a distance as possible in the E-W direction. The two arrays are connected, by radio-frequency transmission lines, to a single receiver at the mid-point, so that their electromotive forces are added together. An arrangement of this kind has a receptivity diagram of the form shown in figure 2, in which maxima alternate with minima. The maxima occur in directions such that the path difference to the two arrays is a whole number of wavelengths, and the directions are thus separated by an angle  $\theta$ , given in radians by  $\theta = \lambda/W$ , where  $W$  is the distance between the aerials. The overall curve which envelops the receptivity diagram represents the receptivity of one of the aerial arrays by itself, and is determined by the size of the single array. Since each array is much smaller than the distance between the two, the angular width of this enveloping curve is much greater than the angular distance between the maxima. As the Earth rotates, the receptivity pattern of figure 2 is carried round with it, and an astronomical source of radiation which subtends a very small angle would be received with periodically increasing and decreasing intensity. If the source subtended an angle comparable with the angle  $\theta$  in figure 2, it

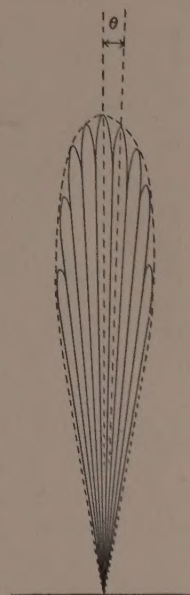


FIGURE 2 — Receptivity diagram of a spaced-aerial interferometer.

would overlap one or other of the minima and the response would not drop to zero; a uniform diffuse distribution of radiation would not produce any periodic variation at all. If, superposed on a general diffuse background of radiation, there were a small source subtending an angle less than  $\theta$ , it would produce an oscillating trace. Two traces of this kind are shown in figure 3, which is a copy of a record obtained on a wavelength of 3.7 m. It reveals the presence of two small sources of radiation. The times *A* and *B*, at which the central maxima occur, correspond to the times at which the plane of symmetry of the aerial system passed the two sources. Their directions can therefore be located to an accuracy comparable with the angle  $\theta$  between two maxima on the

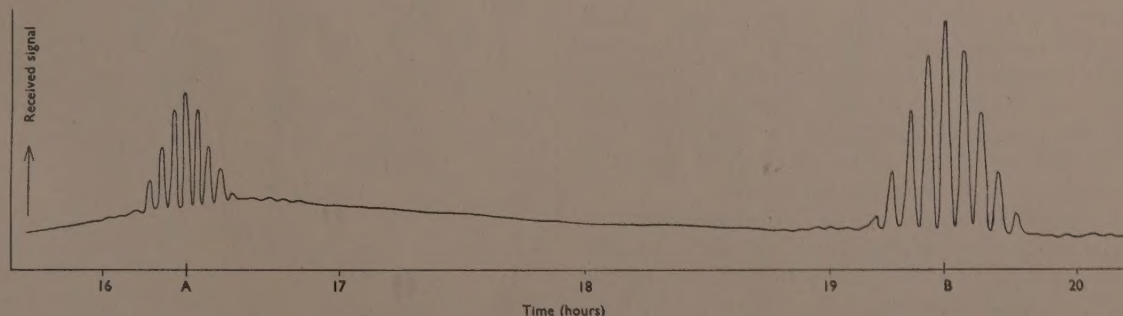


FIGURE 3 — Section of a record obtained with an interferometer system working on a wavelength of 3.7 m. It indicates the presence of two localized sources of radiation superimposed on diffuse background radiation. (By courtesy of The Physical Society.)



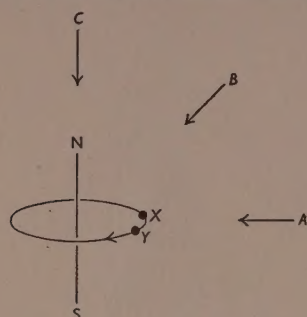


FIGURE 4 - To illustrate how the periodicity on an interferometer record depends on the N-S co-ordinate of the source.

receptivity diagram. It is interesting to note that this angle is given by  $\theta = \lambda/W$ , which is the same as the resolving power of a mirror having a diameter equal to the distance between the aerial arrays. A method of recording with a spaced-aerial system recently developed makes possible even greater precision, of the order of  $0.01 \lambda/W$ .

Although the interferometer arrangement enables the angular position of a source of radiation to be determined in the E-W direction, it may seem at first sight that it does not provide information about the angular position in the N-S direction. This co-ordinate, however, can also be determined. In figure 4, suppose X and Y to represent the two arrays spaced along an E-W line on the Earth and turning round with it. If radiation is incident in the direction A, the difference of the paths to X and Y will alter at a rate determined by the separation XY and the speed of the Earth's rotation, and this rate will determine the time between the maxima on records such as that of figure 3. If, however, the radiation is incident in the direction C, the paths to X and Y will not alter as the Earth rotates. If the radiation arrives in an intermediate direction B, the path difference changes, but at a rate less than that for the radiation from A. As the direction of incidence moves from A to C, the time between successive maxima on the trace becomes longer, and it may be shown that there is a simple cosine relation between the direction of arrival of the waves and the time between maxima. The angle of arrival in the N-S direction can therefore be determined from the periodicity of the interference record.

Figure 6 shows two aerials of the interferometer type which have been used at Cambridge. In one, each of the two arrays A and B consists of eighty dipoles coupled in phase to a transmission line, and erected above a reflecting sheet of wire netting so as to receive best in the vertical direction. The

two arrays are 400 m apart on an E-W line. In the other, the two aerials C and D take the form of small concave mirror aerials. Figure 5 represents diagrammatically the arrangement with the first system, and shows the form of the resulting receptivity pattern on a wavelength of 3.7 m. The record shown in figure 3 was obtained with this aerial. These records indicate the presence of a general background of radiation whose intensity varies with time as different parts of the sky come under observation, with two strong isolated sources which produce the two oscillating traces at times when the receptivity diagram is swept past them by the movement of the Earth.

The radiation from the quiet Sun does not produce an appreciable oscillation on the trace with these aerials, because the angular size of the Sun is such that it covers more than one maximum in the reception pattern. If, however, the angle between the maxima is increased, by decreasing the distance between the aerials, the Sun is no longer large enough to cover two of them, and its radiation produces an oscillating trace on the record. Figure 7 shows records of this kind made with a distance of 10 wavelengths between the

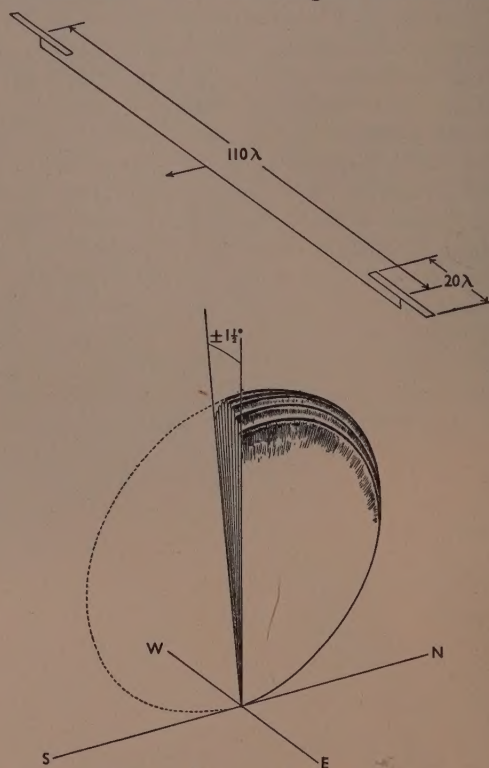


FIGURE 5 - Diagram of the aerial system AB in figure 6 and its receptivity pattern on a wavelength of 3.7 m.

(By courtesy of The Physical Society.)



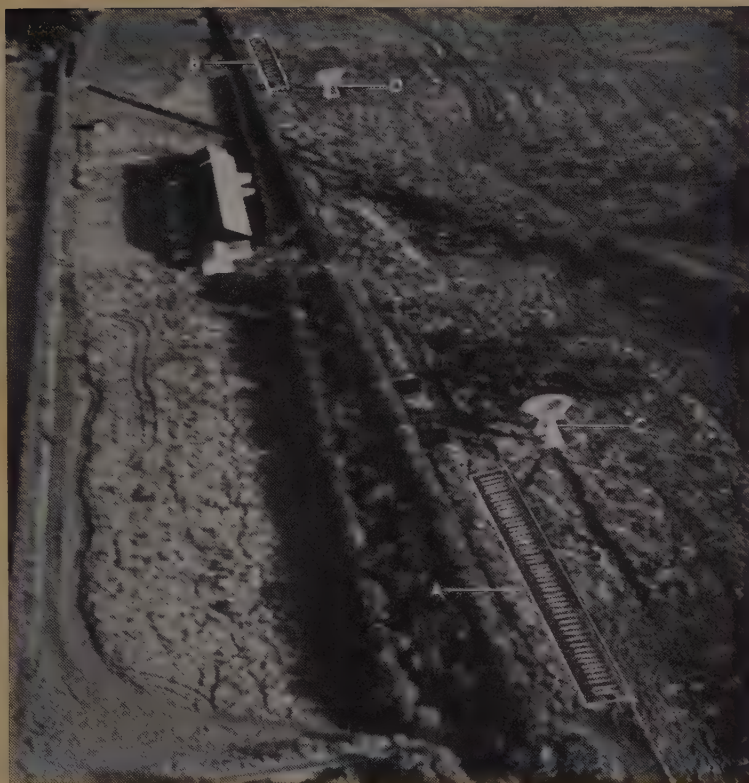


FIGURE 6—Photograph showing two interferometer aerials used at Cambridge. The pair AB has been used on a wavelength of  $3.7\text{ m}$ , and the pair CD on a wavelength of  $1.4\text{ m}$ .

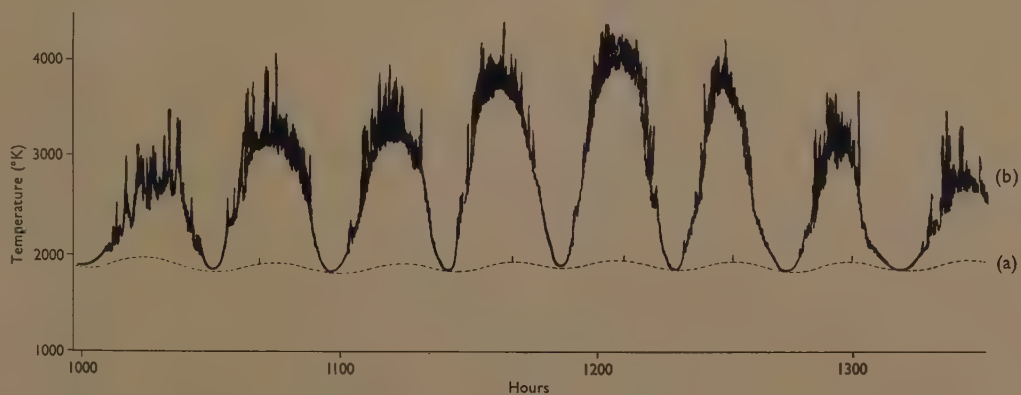


FIGURE 7—Record of solar radiation of wavelength  $3.7\text{ m}$  received on an interferometer aerial of small resolving power. (a) Undisturbed Sun, (b) Sun with active sunspot.

(By courtesy of The Physical Society.)



two aerials. Such records separate the Sun's radiation from that of the galactic background, so that it can be measured and studied independently.

The power received from the Sun when the interferometer aerial is used corresponds to the product of the sinusoidal interferometer pattern and the distribution of radiated power across the Sun's disk. If several sizes of interferometer patterns are used, by using several spacings between the aerials, it is possible to perform a Fourier analysis of the distribution of radiation across the disk. In this way, it has been shown that the radiation from the quiet Sun comes from a disk about twice the size of the visible disk.

In a modified form of the interferometer arrangement, used by workers in Australia, a single aerial array is mounted on the top of a cliff, so as to receive over the sea in directions near the horizontal. A source of radiation at a small elevation is received on the aerial by means of both a direct ray, and an indirect ray reflected from the surface of the sea. The resultant e.m.f. in the aerial is then similar to what there would be if a second aerial array, situated at the image point below the sea, were used in conjunction with the actual array in a system of the kind previously described, and an oscillating trace is produced as a source rises above the horizon.

Each of these types of interferometer has its own advantages and disadvantages. In the cliff type, there are no physical connecting cables between the two effective aerials, since one is only an image, so that problems concerned with electrical matching and with changes in the constants of the cable are not involved; but changes in the level of the sea must be allowed for. Observations can be made only in nearly horizontal directions, and where the refractive effects of the lower parts of the atmosphere may produce important errors of measurement. Although the interferometer which uses two separate arrays avoids this difficulty by receiving predominantly from near the zenith, it is more difficult to construct and maintain because of the need for a cable between the arrays.

#### RESULTS

##### GALACTIC RADIATION

Records of the type shown in figure 3 have

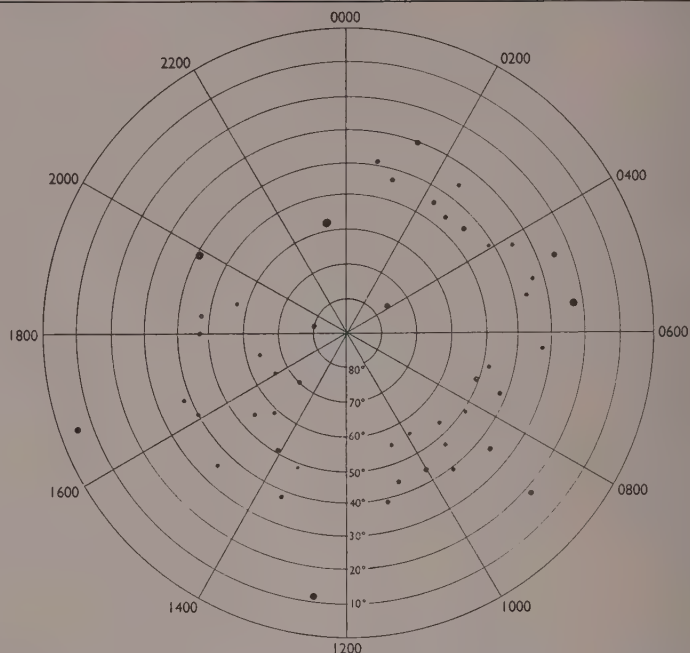


FIGURE 8 — Map showing the position of the radio stars located in the northern hemisphere.

indicated the existence of a large number of discrete sources of radiation distributed throughout the sky, and have enabled their positions to be fixed within the resolving power of the interferometers used. Figure 8 is a map of the sources so far located in the northern hemisphere. The intensities of the sources received are indicated by the size of the dots on the map. The strength of the radiation received at the ground from some of these sources is comparable with that from the Sun; indeed, on a wavelength of 5 m, the radiations from two of them are stronger than that from the quiet Sun.

The discrete sources of radiation which have been detected in this way have been called radio stars. It is interesting to inquire whether they are in fact also visible stars, but we must remember that, on account of the limited resolving power of the radio telescopes, it is not possible to locate the radio stars as accurately as the visible ones. A preliminary examination of the positions of the radio stars shows that there is no relation between bright radio stars and bright visible stars. Thus the two most intense radio stars can be located within regions subtending less than 0.25 square minute of arc, and in these regions there are no visible stars brighter than fourteenth magnitude.

In addition to the radio stars revealed with the interferometer arrangement, there is also a general



background of radiation which cannot be resolved into discrete sources. The distribution of intensity in this unresolved background is found to follow closely the contours of the Galaxy<sup>1</sup> as determined from maps of visible stars, the greatest intensity coming from the galactic plane. It appears that the disk-like assembly of visible stars which forms the Galaxy has associated with it sources of radio radiation which are also distributed throughout this disk, so that we receive most radiation from its plane, just as we receive most light from the plane of the Milky Way.

It is now appropriate to inquire whether the galactic radiation can be explained simply in terms of the sum of the emissions from innumerable radio stars which have not yet been resolved, or whether there is some extended source of radiation not associated with stellar bodies. If the former explanation is adopted, it is necessary to explain why the radio stars at present located are distributed roughly uniformly in all directions, as indicated by figure 8. It appears reasonable to suggest that they are so numerous that, with the present limited resolving power, the more distant weaker stars cannot be resolved, and that only the nearer and stronger ones are detected separately. If these were at distances considerably smaller than the shortest dimension of the Galaxy, they would be uniformly distributed in direction. The situation would be similar to that encountered when visible stars are observed without a telescope; the unaided eye can resolve only those which are comparatively near to the solar system, and which are therefore uniformly distributed in direction, although the sum of the radiation from large numbers of distant stars produces the well-known diffuse radiation from the Milky Way.

Attempts to measure the distances of the brighter radio stars by parallax methods have so far failed owing to the limited resolving power of the radio telescope, but it is thought that the brightest of them are further away than  $10^{13}$  km. This distance is equal to about half that of the nearest visible star, but still only about  $10^{-4}$  times the shortest dimension of the Galaxy.

If the observed radio stars are taken as typical ones, and if it is assumed that radio stars are

dispersed throughout the Galaxy with a density comparable with that of visible stars, and with the same statistical distribution of intensity, it is possible to account for the observed intensity of the background radiation. Until some definite evidence about the distances of the nearer radio stars has been obtained, however, it is not possible to exclude other sources for the galactic radiation.

The fact that the radiation comes from the galactic plane, and hence probably from sources inside the Galaxy, suggests that the Galaxy is probably also radiating outwards into space. If this were so, we might expect other galaxies to send some measurable radiation to us. Four of the nearest extra-galactic nebulae do in fact fall near the observed positions of four radio stars, and it seems likely that here we are observing the total radio emission from these remote galaxies. This result indicates that whatever mechanism is responsible for the radio emission in our own Galaxy occurs in other galaxies also.

#### SOLAR RADIATION

We now turn to the radio radiation received from the Sun. Its strength fluctuates considerably, and periods of intense radiation are associated with the passage of sunspots across the central part of the disk. Since radio-astronomical observations began to be made, sunspots have been so numerous that it is difficult to decide precisely what is the intensity from the undisturbed Sun, but there are now sufficient measurements to make it clear that this intensity varies with the wavelength of the radiation. The important theoretical significance of this fact will be discussed later. The distribution of emission across the quiet solar disk has also been determined by the Fourier method previously described, and it is found that at metre wavelengths the radio Sun is about twice as large as the optical Sun, and that, in contrast to what is observed on optical wavelengths, the radiation falls off gradually near the edge.

When the Sun is known, from optical observations, to be disturbed, the radio radiation is often considerably enhanced. The increase is most marked on the longer waves (10 m), where it may be  $10^4$  times the normal,<sup>2</sup> whereas on a wavelength of 10 cm it is unusual to find it increased even to twice the normal value. The enhanced radiation is characterized by rapid fluctuations, like those shown in figure 7*b*, and occasionally sudden bursts of even greater intensity are observed. These

<sup>2</sup> The increase is sometimes so great that serious interference is observed on television and radar receivers.

<sup>1</sup> The Galaxy is the name for the immense disk-like assembly of stars of which the Sun and the solar system form a part. It is thought to have a diameter of about  $10^{18}$  km and a thickness of about one-fifth of that figure; the solar system is about one-third of the way out along a radius. The Milky Way represents the unresolved distribution of stars seen when we look out in the plane of the Galaxy.

bursts are frequently associated with solar flares of the type which are observed in the spectrohelioscope, and which are known to accompany fading of radio transmissions on the Earth.

Experiments with interferometer aerials have shown that the sources of enhanced radiation coincide fairly accurately with visible sunspots. Observations have also been made at times of eclipses in a search for localized sources of radiation on the solar disk, and there is some evidence that regions of intense radiation occur where no sunspots are visible. The radiation from sunspots is most intense when they are in the central part of the Sun's disk, and it appears that the radiation, at any rate at the longer wavelengths, is emitted in a cone of semi-angle about  $15^\circ$  with its axis normal to the solar surface.

The polarization of the Sun's radiation has been studied in some detail. There is no evidence that the radiation from the quiet Sun is polarized, but from sunspots it has been found to be circularly polarized, sometimes with one sense of rotation and sometimes with the other. Although it is probable that the direction of polarization is related to the magnetic polarity of the spot, it has not yet been possible to establish any clear connection. The main difficulty is that most spots are complex, with different parts of opposite magnetic polarities.

#### THEORIES

Now let us inquire how these facts can be explained. We first note that the radiation from a full radiator at a high temperature would include an appreciable amount of energy in the region of radio wavelengths, and if this radio radiation were

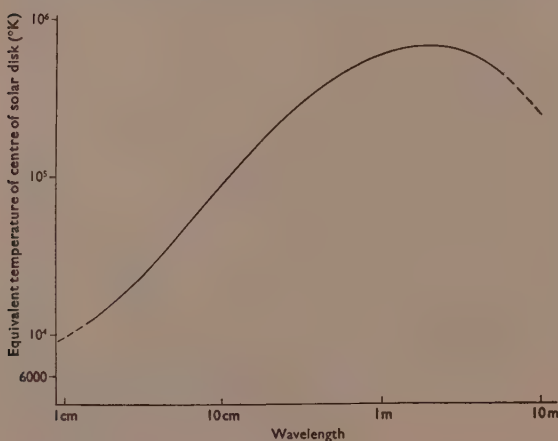


FIGURE 9—To show how the emission from the undisturbed Sun depends on the wavelength. The intensity of the received radiation is expressed in terms of an equivalent temperature.

really a part of the continuous spectrum it would have the white-light characteristics of noise which are observed in the solar radiation. If we assume that the quiet Sun radiates from an area somewhat larger than the solar disk (as shown by experiment), we can use the observed intensity of the radiation to calculate the temperature of the source. The equivalent temperature for the centre of the solar disk is then found to depend on the wavelength of the observed radiation, as shown in figure 9. It is clear from these results that the equivalent temperature for the emission of radio waves is greater than that ( $6000^\circ\text{K}$ ) deduced from observation of the visible light from the Sun.

The fact that the radiation comes from an area about twice as large as the visible disk suggests that it might originate in the solar corona, and this suggestion becomes very reasonable if it is also remembered that recent spectroscopic evidence has led to the belief that coronal temperatures are of the order of  $10^6$  degrees K. The solar corona is supposed to be completely ionized, so that it consists of free electrons colliding—comparatively infrequently—with the positive nuclei of atoms. This gas of colliding electrons is in many respects similar to the terrestrial ionosphere, and ordinary ionospheric theory can be used in the investigation of its behaviour.

In order to examine in detail the way in which the intensity emitted on different wavelengths might be expected to vary across the Sun's disk, it is convenient to reverse the problem and consider the incidence of a series of rays from outside the Sun at different angles. If the electron density and temperature were known at all heights in the solar corona, it would be possible to compute the absorption along each of these rays. Then by the principle of thermodynamic reversibility it would be possible to determine the intensity of the radiation emitted in each of these directions, and hence the distribution of brightness across the Sun. By comparing the theoretical results with those determined experimentally, an attempt might then be made to find how the electron density and temperature actually vary with height. Up to the present, it has not been possible to set up a fully satisfactory model of the whole solar atmosphere, although a model of the lower levels, the chromosphere, has been deduced in this way. Figure 10 shows the results obtained.

After having said that there is a reasonably good theory for the emission of radio waves from the quiet Sun, we now have to admit that there is no correspondingly simple explanation of the



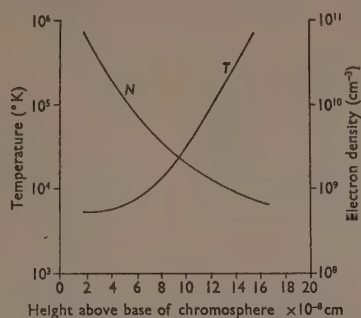


FIGURE 10—*The electron density (N) and temperature (T) in the model chromosphere.* (By courtesy of Science Progress.)

enhanced radiation from sunspots. Two facts of importance must be explained by any theory. First, the observed circular polarization of the radiation suggests that the magnetic field of the spot plays an important part in the emission, since free electrons perform circular orbits round the magnetic field. Second, since the greatly enhanced radiation comes from a measurably small region near the sunspot, it must correspond to a very high temperature: indeed, equivalent temperatures greater than  $10^{10}$  degrees K are deduced. Two different types of theory have been suggested. On one, which we call the equilibrium theory, it is supposed that the radiation is produced by electrons moving with randomly directed (gas-kinetic) velocities as great as they would have if they were in equilibrium with gas at a temperature of  $10^{10}$  degrees K. It is suggested that the electrons have gained this energy by the action of electromagnetic forces produced, for example, by the growth of the magnetic fields of sunspots. The energies produced by quite moderate fields can be large, because the electrons in the Sun have large mean free paths. If very energetic electrons of this kind were produced, they might radiate as observed, and the polarization of the radiation would arise by a process analogous to that which produces different absorption of right- and left-handed circularly polarized waves in the terrestrial ionosphere.

On the other type of theory, which might be called the coherent oscillation theory, it is assumed that some process causes a number of electrons to oscillate in phase, so that they produce a coherent oscillation. The great equivalent temperature of a sunspot would then indicate not a great temperature, but an ordered electron motion, just as the great intensity of the wave from a broadcasting transmitter is a consequence of the ordered motion of the electrons in the aerial and not of their great

energy. The magnetic field of the spot might cause the coherent oscillations to be circular, so that circular polarization would be emitted.

When we turn to consider the galactic radiation, it cannot be said that any generally accepted theory has yet been proposed. It has already been mentioned that, on a statistical basis, it is reasonable to suppose that the apparently diffuse radiation from the Galaxy comes predominantly from an unresolved assembly of radio stars having the statistical characteristics of those already observed. It is, however, possible that some of this diffuse radiation originates in interstellar matter, although so far no explanation has been put forward which accounts for more than a small fraction of it.

It is found that the radio emission from an average radio star is at least  $10^8$  times as great as that from the undisturbed Sun. It is even 100 times as great as that from the Sun when it is most disturbed, but the great constancy of the radiation from each of the fifty or so radio stars so far observed makes it seem unlikely that they emit by the same mechanism as that which occurs on the disturbed Sun. We must conclude that the radio emission from radio stars requires some mechanism capable of giving much more intense emission than occurs in the Sun. At the same time we notice that, as compared with the Sun, their visible emission is relatively very weak. They behave as if they had photospheres which are much cooler than the Sun's and coronas which are much hotter.

#### THE FUTURE OF RADIO-ASTRONOMY

It appears likely that, in the immediate future, experimental radio-astronomers will concentrate their attention on methods of achieving increased resolving power: the development of larger interferometer aerials should allow the observation of more radio stars, and may enable their parallaxes or diameters to be determined; the use of larger 'pencil beam' aerials should provide important information on the distribution of the background radiation from the Galaxy, and also on the radiation from extra-galactic nebulae.

Plans for the construction of a large radio-telescope of the latter type at Manchester have recently been announced. This telescope will have a diameter of 250 ft., and will be rotatable so that it can be directed towards any part of the sky. It will therefore not only have a greater directivity than the present large Manchester aerial, but will be available for observing sources at all declinations, and not only in the zenithal strip.

# Sir William Ramsay (1852-1916)

M. W. TRAVERS

It is over fifty years since neon was first isolated by Ramsay and Travers, and here Professor Travers—now *doyen* of British chemists—gives a personal account of the work of his celebrated colleague, who added a whole family of elements to the Periodic Table. Few journals can have had the privilege of publishing, half a century after the event, the story of a great scientific discovery specially written by one of its chief participants. Our pleasure in Professor Travers' article will assuredly be shared by all readers of ENDEAVOUR.

William Ramsay was educated first at the Glasgow Academy, then took a three-year junior course at Glasgow University. At the age of 16½ he had received an education in classics, but the course included little mathematics and no science. He had had lessons in French and German, and by following the Bible readings in church in those languages he had acquired a working knowledge of both of them. He had a musical ear, was a competent pianist, and had developed the unusual accomplishment of whistling classical music to his own accompaniment. He was clever with his pencil, making excellent sketch portraits, and could write amusing verses. Athletic, he was not fond of ball games, though he could play both golf and tennis fairly well; but he was always happy on or in the water, and was a remarkable underwater swimmer. He had a good memory for names and faces, enjoyed company, and made lifelong friendships. Success in any branch of life might well have been predicted for young Ramsay.

The object of his education had been entry to the ministry, but on leaving the university he decided to be a chemist. He knew no more chemistry than he had learned by carrying out experiments at home with his friend Henry Fyfe, but he had been brought up in a scientific atmosphere. His father, trained as an engineer, was interested in science, and particularly in the work of his brother Andrew, the eminent geologist, with whose family Ramsay was intimate. In May 1869 he entered the laboratory of the Glasgow city analyst, remaining there sixteen months and becoming a competent analyst. During the winter he attended lectures on chemistry in the university.

It had been his intention to go to Heidelberg in the autumn, but owing to the outbreak of the Franco-German war he remained in Glasgow, working in Sir William Thomson's laboratory and attending his lectures. In April 1871 he went to Tübingen to work under Fittig. His letters to his

parents show that he enjoyed the university life, and the vacation walks through south Germany, Switzerland, and Austria. He carried out a research on the nitrotoluic acids, thus arousing an ambition to explore further in the widening field of organic chemistry.

He won his doctorate in Tübingen, and returned home to take up an appointment as assistant to the professor of technical chemistry in Anderson's College, Glasgow; two years later he was appointed tutorial assistant in the chemistry department of Glasgow University. One cannot believe that Ramsay enjoyed holding tutorial classes for 200 medical students in batches of fifty; but one equally cannot imagine Ramsay being unhappy in any position in which he had opportunity, even if limited, for research work and for travel in the vacations. In Anderson's College, the pursuit of organic chemistry was not supposed to be consonant with the duties of a technical chemist, but at the university the fact that a former professor had been engaged in the study of bone oils, and had left a large stock of distillation fractions consisting of pyridines, provided material for investigation ready to hand. Ramsay published several papers on the carboxylic acids resulting from oxidation of the pyridines, demonstrating their relationship to the benzene carboxylic acids. McKendric, the professor of physiology, joined with Ramsay in the study of the pharmacological properties of the pyridines, which led Ramsay, with Dobbie, to study the oxidation products of the quinine alkaloids. That these bodies gave oxidation products similar to those of the pyridines has been the basis of much work on alkaloids. Dobbie (afterwards Sir James) was the first of a succession of junior collaborators who were associated with Ramsay in his researches.

The circumstances which led to the change in Ramsay's interests from organic chemistry to what was later to be known as physical chemistry are



interesting. James Thomson, brother of Sir William Thomson, had been associated with Andrews in Belfast in his work on the critical state, and, since his appointment as professor of engineering in Glasgow in 1873, had continued to take an interest in the subject. Thomson formed a friendship with J. B. Hannay, a man who, had he not given up chemistry before he was thirty, might have come to be regarded as one of the most brilliant experimentalists of his age. Hannay in the late seventies carried out some remarkable investigations, proving that the solubility of salts in fluids showed no discontinuity in passing through the critical temperature, and that the rise of a liquid in a capillary tube diminished as the temperature rose, becoming zero at the critical temperature. These beautiful experiments demonstrated the principle of the continuity of the gaseous and liquid states, and the existence of the definite critical point. Ramsay entered into controversy with Hannay and was defeated, but he learned much from Hannay which was of service to him in his work in the same field, in which he in turn became recognized as a master.

Ramsay applied for several appointments, and at 28 years of age was becoming disappointed, when in February 1880 he was appointed professor of chemistry in University College (now the University), Bristol. He at once made his mark as a leader, and in October 1881, on the retirement of Alfred Marshall (afterwards eminent as an economist) from the post of principal, he was appointed to succeed him, retaining at the same time his chair of chemistry. This gave him the opportunity of embarking on the happiest venture of his life, marriage with Margaret Buchanan. Few men could have succeeded in carrying what he afterwards called the incubus of college administration and in establishing a research school, which he succeeded in doing. It proved a hard task; the College was ill-supported by the public, but Ram-

say showed a genius for co-operation, and soon earned the admiration and affection of the eminent men who formed the council—the chief of whom was Benjamin Jowett, the famous Master of Balliol—and also of his colleagues on the staff, an extremely able group of men.

Ramsay was assisted in the chemistry department by a single demonstrator, the post being held by young men, on the look-out for permanent

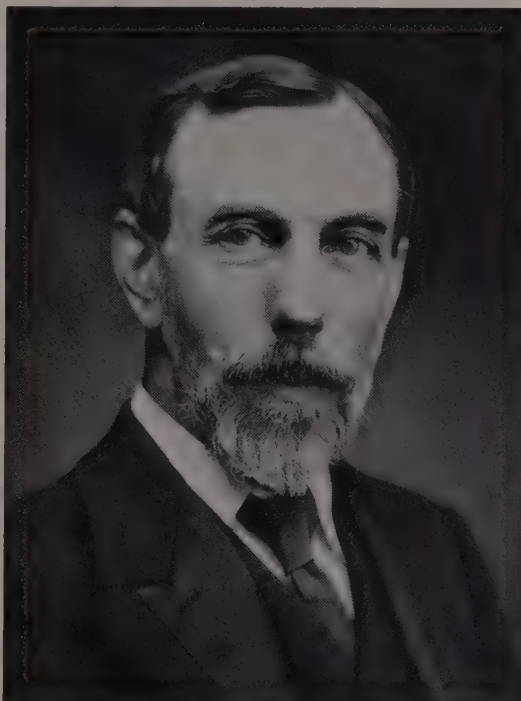
appointments, who received honoraria. Sydney Young, who succeeded to this post in 1882, found Ramsay engaged in the determination of the volumes of vapours at their boiling points, and in the measurements of the vapour pressures and critical constants of benzene and ether. Young, who had studied in Manchester and Strasburg, and was a good experimentalist, was already interested in the phenomenon of the evaporation of ice. They joined forces, and their first work led to the verification of the theory of the relationship between the vapour pressures of liquids and solids which had been put forward by James Thomson.

This was followed by

the publication of a series of papers under the title 'On Evaporation and Dissociation,' which are regarded as classical. Sydney Young was the second of the junior collaborators associated with Ramsay.

Among Ramsay's activities while principal of the College was the initiation of a movement to secure government aid to the university colleges.

In 1887, Ramsay was appointed professor of chemistry in University College, London. His predecessor, A. W. Williamson, had taken an active part in the fifties in the controversies over the structure of simple organic compounds, and on the conduction of electricity through solutions of salts, but had long since given up research in favour of university politics; the school was dead. Ramsay's staff consisted of himself with two juniors, technically his assistants and paid by



*Sir William Ramsay*



Sir William Ramsay



(Spy' cartoons from 'Vanity Fair', by courtesy of The National Magazine Company Limited.)

Sir William Crookes



himself. The laboratory was larger than that at Bristol, but ill designed and ill equipped. However, Ramsay was at last in London, at the centre of things and sure of himself: also he had shed the incubus of administration.

He soon began to build up a research school. One of the most interesting groups of investigations, begun in the late eighties by H. Picton and S. E. Linder, and originating in work which Ramsay had carried out in Bristol on Brownian movement, was on pseudo-solutions, and resulted in the discovery of many important facts regarding the behaviour of colloids. In 1890, a peak was reached in the controversy over the new theory of ionic dissociation in solution, of which Arrhenius and van 't Hoff were the originators and Ostwald the prophet. Battle royal was joined at the meeting at Leeds of the British Association for the Advancement of Science, Ramsay siding with the modernists, who were bitterly opposed by H. E. Armstrong and a strong group of British chemists. I need not enter into details of the controversy, which are generally known. Ramsay and his staff and students were not actually engaged in researches bearing on the subject, but Ramsay kept up a correspondence with Ostwald, in which problems of solution were often discussed.

Ramsay was still interested in the state of aggregation of liquids and vapours, and his personal investigations continued in the field opened up at Bristol. With John Shields, he carried out an investigation to determine the molecular aggregation of liquids by measuring the variation of surface tension with temperature. The molecular weights of metals in solution, and the densities of vapours, also engaged his attention.

By 1894, Ramsay was already well known in the scientific world. He was regular in attendance at scientific meetings, particularly of the British Association, and travelled widely on the Continent. Speaking French and German fluently, he made in Europe a number of intimate friends and innumerable acquaintances. Twice he had visited America, and was equally well known there. In 1894 he was on the point of becoming famous.

I have told the story of the discovery of the rare gases many times, and always find it more difficult to tell in a few words. Three men were associated with the discovery, for which there is ample honour to go round. In 1785, Henry Cavendish—that prince of experimentalists—had found that when an electric discharge was passed through air to which, using modern terms, oxygen was added, confined over potash solution, its volume dimi-

nished, and saltpetre was formed in the liquid. But, for however long the discharge was passed, after absorbing the residual oxygen there remained behind a small bubble of gas. This discovery was overlooked for more than a hundred years.

In September 1892, Lord Rayleigh wrote a letter to 'Nature' saying that he had found that atmospheric nitrogen was always slightly denser than chemical nitrogen, from whatever source it was obtained. He asked if anyone could explain this peculiar fact. On 19th April, 1894, he gave the Royal Society a very full account of his work on the density of nitrogen, but attempted no explanation of the difference in densities. After the meeting, Ramsay had some conversation with him, which he described in a letter to his aunt written four months later. Ramsay said that he had speculated on the cause of the difference in the densities, and was inclined to doubt the accuracy of the work. But, he continued, Lord Rayleigh 'gave a paper to the Royal Society, showing numbers about which there could be no reasonable doubt. I asked him if he minded my trying to solve the mystery. He thought that the cause of the mystery was a light gas in non-atmospheric nitrogen; I thought that the cause was a heavy gas in atmospheric nitrogen. He spent the summer in looking for the light gas; I spent July in looking for the heavy one. And I have succeeded in isolating it. . . .'

We must now return to the month of April. A few days after his conversation with Lord Rayleigh, Ramsay set an assistant to work on an experiment which he had mentioned, treating atmospheric nitrogen with heated magnesium metal, which was known to combine with nitrogen, and which might not combine with any heavier gas possibly present. At a meeting of the Royal Society on 24th May, he was able to tell Lord Rayleigh privately that the nitrogen was heavier after than before treatment, and to a greater extent than could be ascribed to experimental error. He wrote to him on the subject the same evening, adding 'Has it occurred to you that there is room for gaseous elements at the end of the first column of the Periodic Table?'

Then, as soon as college examinations were over, he took up the problem himself. Setting up an apparatus for passing atmospheric nitrogen backwards and forwards between two glass gas-holders through heated tubes containing magnesium turnings and copper oxide, with necessary arrangements for absorbing water vapour and

carbon dioxide, he reduced 23 litres of gas very rapidly to 1.5 litres. Using a smaller apparatus, the volume was reduced to one-eightieth of the original, and the density of the gas had increased from 14 to 16.1. Finally, after passing the gas repeatedly over fresh magnesium, the surface of which did not appear to tarnish, the density rose to 19.085. A sample of the gas was sent to William (later Sir William) Crookes, who reported that the spectrum was new. Then, on 4th August, Ramsay wrote to Lord Rayleigh a letter beginning with the words 'I have isolated the gas at last...'; and believing that Lord Rayleigh was not interested in the suggestion that the density of atmospheric nitrogen was due to the presence in it of an unknown heavy gas, he wrote up his results in the form of a paper for the Royal Society. At the moment of finishing the paper, on 7th August, he received from Lord Rayleigh a letter saying that he had repeated the Cavendish experiment and obtained 'A residue of 0.3 cc. of gas which was neither nitrogen nor oxygen (no hydrogen).'

It was at once agreed that they should join forces. The manuscript of Ramsay's paper was put aside, coming to light only after the death of Lady Ramsay in 1936. Lord Rayleigh abandoned his idea of making a communication to the British Association, and, instead of this, a note on the discovery appeared under their joint names. It may be said that it awakened more incredulity than interest; and this was not allayed till a full account of the discovery and properties of argon was given to a crowded meeting of the Royal Society on 31st January, 1895. The density of the gas was then given as 19.95, that of oxygen being 16, and as the value of the specific heat at constant volume showed that it was monatomic, its atomic weight was 39.9. It appeared to be a completely chemically inactive element.

On the day following the reading of the Royal Society paper, Henry Miers, of the British Museum, thinking that the information might give Ramsay a lead in his investigation into the possible combination of argon with other elements, wrote to him calling to his attention that Hillebrand of the U.S. Geological Survey had shown four years earlier that many uranium-containing minerals gave off, on heating, or on treating with acid, a gas supposed to be nitrogen. It was suggested that this gas might be argon. Ramsay obtained a sample of one of these minerals, clèveite, and six weeks later, when he had completed some final experiments on argon, he repeated Hillebrand's experiment. It was clear that the spectrum of the

gas was new, and that the very bright yellow line in it was not the sodium D line. Ramsay had a new gas, which he called, provisionally, krypton (though this name was finally given to still another inert gas). He sent a sample to Crookes, who identified the yellow line with that of the hypothetical element helium observed in the Sun's spectrum during the eclipse of August 1868.

The gas was found to have a density of about 2, and being monatomic, like argon, its atomic weight was about 4.

Passing over two years, we come to August 1897, when Ramsay, as president of the chemistry section of the British Association, meeting in Toronto, delivered an address with the title 'An Undiscovered Gas.' He showed that, in accordance with the Periodic Law, there should exist a gas having properties intermediate between those of helium and of argon. Its atomic weight should be 20, and its density 10. But, as he said, 'searching for it was like looking for a needle in a haystack. Modern science, with the aid of suitable magnetic appliances, would make short work of the proverbial needle. But here is a supposed unknown gas, endowed no doubt with negative properties, and the whole world to find it in.' Ramsay and Morris Travers had already spent two years in the search, and at the end of the year 1897 they were driven to the conclusion that the atmosphere might yet be the hiding place of the unknown gas. Unsuccessful attempts had already been made to separate argon into light and heavy constituents by fractional diffusion, but now another method presented itself—liquefaction of the argon, and fractional distillation of the liquid. What was in those days a very large quantity of argon was isolated. It was liquefied in a bulb cooled in liquid air, and the most volatile fraction was separated. When an electric discharge was passed through the gas, the blaze of crimson showed that the end of the search was in sight.

Between May and July 1898, it was found that atmospheric air contained not only argon but four other gases. Krypton and xenon, ultimately found to have atomic weights close to 80 and 128 respectively, were easily liquefied, and were relatively easy to separate and to obtain reasonably pure. But the volatile fraction was a mixture of argon and helium with the unknown gas, named neon, and the mixture could not be liquefied using liquid air. However, in July 1900, pure neon was separated from the argon and helium by means of liquid hydrogen; it was found to have a density 10 and an atomic weight 20, as predicted. The



five rare gases fitted into their appropriate places in the Periodic Table.

The discovery of the rare gases was a stepping stone to the work on radium, and particularly to that of Rutherford which followed almost immediately on it. An early discovery by Rutherford was that radioactive change in thorium gave rise to a gas, which was itself radioactive but chemically inactive, though capable of being condensed out of an admixture with air at liquid-air temperature. Rutherford and Soddy found that radium gave a similar emanation, and Soddy came from Montreal to join Ramsay in London in the study of the emanation by methods developed during the work on the rare gases. They found that the five rare gases already known were not radioactive; and they confirmed the fact that the radium emanation, later called radon, resembled the rare gases in its chemical inactivity. Their most important work was their demonstration that radon on disintegration yielded helium, confirming the view put forward by Rutherford that the presence of helium in uranium- and thorium-containing minerals was due to the fact that it was a product of radioactive change.

To finish the story of the rare gases we must pass on to the year 1909. The work of Ramsay and Soddy had fully confirmed the suggestion of Rutherford that radon belonged to the rare-gas group. It was without chemical properties, and there remained the investigation of its physical properties, particularly its density, from which its atomic weight could be deduced, and the mechanism of its formation from radium, which appeared likely to be represented by the equation:



Between 1909 and 1912, Ramsay and Whytlaw-Gray determined the atomic weight of radium, and the density, vapour pressures, liquid volumes, and critical constants of radon. Ramsay describes the remarkable density determination in the following words: 'The volume of radon in equilibrium with one gram of radium is 0.6 cubic millimetre; and Ramsay and Whytlaw-Gray had only 1/6th of this amount at their disposal. Its weight was found to be 1/2000 milligram, and, in order to reach reasonable accuracy, the balance should show 1/200th part of this weight, or 1/100,000 milligram, turning with 1/500,000 milligram.' He describes the balance, which was made from very light silica rods, and the operation of it, in some

detail. Five experiments gave, on the assumption that radon was monatomic, a mean value 223 for the atomic weight. This is between 3 and 4 units less than their own value for the atomic weight of radium, confirming the theory represented by the above equation.

In the early years of the century, it was recognized that elementary atoms consist largely of electrons, or particles of negative electricity. Nernst had suggested that the process of ionic dissociation in solution involved, in the case of sodium chloride for instance, the transfer of an electron from the sodium atom to the chlorine atom, a positive or negative charge involving a loss or gain of an electron. In his presidential addresses to The Chemical Society in 1908 and again in 1909, Ramsay put forward the view that a mobile electron might itself furnish the mechanism of the chemical bond, foreshadowing the idea that the chemical bond resulted from the sharing of pairs of electrons.

Ramsay also put forward the idea that using 'energy in an enormously concentrated form as radon it should be possible to remove electrons from atoms to such an extent as to degrade them into atoms of lower atomic weight.' I cannot follow him in these speculations and investigations, or attempt to show how far the speculations were justified—as indeed they were to a great extent—and worthy of Ramsay's genius, or why the experimental methods at his command were inadequate. But in speaking of his work on radon, I must mention his investigations with physiologists and surgeons on the applications of radon in the treatment of malignant disease. His name is hardly mentioned in the literature in this connection; but much may be learned from his correspondence of the time and thought which he gave to this work for the benefit of humanity.

Ramsay's researches on the rare gases brought him international fame, and honours were conferred on him by universities and learned societies throughout the world. He was knighted in 1902. In 1904 he was awarded the Nobel Prize for chemistry; very appropriately the prize for physics in the same year went to Rayleigh.

A man of Ramsay's quality must have critics, and, as 'contumely is an essential ingredient of all true glory,' some of them must be inimical. But the principle which he tried to live up to was summed up in the two words, 'Be kind,' and the number of his friends of all nationalities was legion.

# Lysogenic bacteria, II

ANDRÉ LWOFF

In the first part of this article, (ENDEAVOUR, II, 72, 1952) it was shown that lysogenic bacteria perpetuate a specific particle, the probacteriophage, which is endowed with genetic continuity and is a non-infective and non-pathogenic precursor of bacteriophage. In a lysogenic strain, certain bacteria multiply normally, neither producing nor liberating bacteriophages; others produce bacteriophages, which are liberated by lysis. This poses the question of identifying the factors responsible for the production of bacteriophage—that is to say, the transformation of probacteriophage into bacteriophage.

According to one hypothesis, production of bacteriophage results from a mutation. Mutation would occur modifying the unstable equilibrium between bacterium and bacteriophage, and initiating bacteriophage production. This is a hypothesis both simple and easy. It is a sacrifice to the genes, those large molecules methodically arranged on the chromosomes; those specific, all-powerful, and indispensable units which sometimes reproduce themselves normally, sometimes undergo changes the nature of which we do not understand; those large and irritating molecules which the experimenter can modify only in the most unpredictable way as a result of mass bombardment. However, in certain of the experiments with micro-drops described in the first part of this article all the bacteria multiplied, whereas in others all, or at least a substantial proportion, lysed. Observations of this kind lead to the firm conviction that production of bacteriophages depends not upon the vagaries of the genes but upon the nature of the medium. An attempt to support this belief experimentally led to a very long series of experiments with micro-drops, but the results were negative. We then decided to study the kinetics of bacteriophage production in mass cultures, and it at once became apparent that there are considerable variations in the course of the development of a bacterial population.

Before considering these studies a word of explanation is necessary. When micro-organisms develop in a given medium, the latter is continuously changing. Some substances are absorbed by the bacteria, others are excreted. The oxygen tension, the oxidation-reduction potential, and other factors undergo important variations. A medium of constant composition can be maintained only by such arrangements as those of Monod [2], in which a steady supply of new medium exactly compensates for bacterial growth.

Under these conditions the ratio of bacteriophage particles to bacteria remains constant at roughly unity. Under ordinary cultural conditions, however, in a tube or in a conical flask, the ratio varies considerably, even when aeration is arranged. At the beginning of development it varies between 0.1 and 1. Sometimes the optical density of the cultures falls by perhaps one-third, bacteriophages making their appearance at the same time; about one hundred bacteriophages are liberated for every bacterium which disappears. The ratio bacteriophages : bacteria may then reach 50 or more. According to circumstances, the ratio may thus vary within a range of 1 to 500.

Having thus firmly convinced ourselves that external factors determine bacteriophage production, it was necessary to define them.

The lowering of optical density as a result of lysis was observed only in well developed cultures having perhaps  $1.5$  to  $2 \times 10^8$  bacteria per cubic centimetre. Under our experimental conditions it follows a fall in the rate of growth due, directly or indirectly, to lack of oxygen. But a diminution in oxygen tension alone does not suffice to induce lysis, for addition of reducing agents had no effect. After many months of work, we were forced to the conclusion that two or more factors are involved, among which are the oxidation-reduction potential and the modification of the medium as a result of the growth of the bacteria themselves.

## RADIATION SHOCK TREATMENT

It was decided to expose cultures to ultra-violet irradiation, and a culture of *B. megatherium* in a medium containing yeast extract was divided into four parts. One served as a control, and the other three were exposed for different lengths of time to the radiation; the subsequent growth of the bacteria was followed with the help of an electrophotometer.



For some fifty minutes, the irradiated cultures behaved in the same way as the control. By the seventieth minute, however, the irradiated bacteria had disappeared, whereas the control showed no lysis. Titrations indicated that each of the lysed bacteria had liberated about a hundred bacteriophages [1].

This experiment was repeated thousands of times. On each occasion, after irradiation, the culture continued to grow with reduced speed, the optical density being increased from two to four times. Lysis began after about forty-five minutes. All the bacteria disappeared within about twenty minutes, during which time bacteriophages appeared in the medium.

If irradiated bacteria are placed in micro-drops they can be seen to divide, or at least to form a dividing membrane. The units of the filaments so produced lyse themselves at intervals of a few minutes, each producing about a hundred bacteriophages. It is clear, therefore, that bacteriophages are produced by all the bacteria, and are liberated by lysis.

We thus arrived at a means of inducing the production of bacteriophages in a bacterial population as a whole. It remained to study the conditions most efficacious for this kind of shock treatment, and to elucidate the mechanism of its action.

The ultra-violet radiation was produced by a low-pressure, high-voltage quartz lamp; 90 per cent. of the light corresponded to a wavelength

of 2537Å, which is also the point of maximum absorption of nucleic acids. The efficiency of ultra-violet radiation of other wavelengths has not yet been studied. X-rays have effects similar to those of ultra-violet light.

It was tempting to suppose that the causative agents act by bringing about the lysis of the bacteria, which thus liberate bacteriophages. However, there are many arguments against this supposition. Lysis by lysozyme does not liberate bacteriophages; *B. megatherium* is strictly aerobic, and under anaerobic conditions it lyses rapidly, but without liberation of bacteriophages; non-lysogenic strains do not lyse after irradiation.

Irradiation seems to act as a trigger initiating the development of probacteriophage into bacteriophage, this development causing bacterial lysis.

#### THE LATENT PERIOD

In an ordinary system—virulent bacteriophage and sensitive bacteria—the latent period is that between the moment when the bacteriophage penetrates the bacterium and the moment when the latter is lysed with liberation of bacteriophages. This period is essentially characterized by an arrest of bacterial growth, corresponding with a cessation of syntheses by the bacteria. They no longer synthesize either ribonucleic acid or deoxyribonucleic acid. Their respiration remains constant. They are incapable of synthesizing enzymes, in particular the so-called adaptative enzymes. After a quiescent period of some minutes the system begins to manufacture deoxyribonucleic acid, but of the type exclusively associated with the bacteriophage.

In a lysogenic system the latent period is that between shock treatment of the type described above, and lysis. Microbial growth continues, but at a steadily diminishing rate. Respiration increases, ribonucleic acid is synthesized, and enzymatic adaptation is possible. The amount of deoxyribonucleic acid in the system remains constant for roughly the first half of the latent period, then increases very rapidly up to the moment of lysis [3].

In an ordinary system, it is as though the bacteriophage turned to its own advantage practically all the bacterial metabolism. In an active lysogenic system the competition is manifestly less severe, a fact which can be demonstrated with the help of lysogenic *Pseudomonas pyocyanea*. The quantity of glucose put at the disposal of the bacterium per unit of time—the regimen—is constant

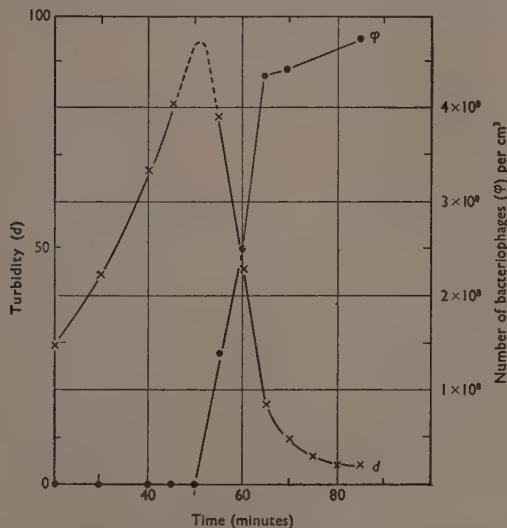


FIGURE 1—Graph showing the relationship between turbidity ( $d$ ) and number of bacteriophages ( $\phi$ ) in a lysogenic culture of *B. megatherium* which has been irradiated with ultra-violet light. The time is measured from the cessation of irradiation.

throughout any one experiment, but varies from one experiment to another. If there is an excess of glucose, bacterial growth after induction is as with *B. megatherium*. With a much reduced regimen, however, bacterial growth does not occur; the glucose is entirely utilized by the bacteriophage. For a bacterium of *P. pyocyanea* to double itself it must have  $2 \times 10^{10}$  molecules of glucose; for it to produce one hundred bacteriophage particles it must have  $4 \times 10^9$  molecules [4]. Whatever the conditions, the bacteriophage takes up a definite quantity of glucose. The percentage of glucose absorbed by the bacteriophage, compared with the total bacterial metabolism, varies according to the conditions from 20 to 100 per cent. In all cases it is seen that the bacteriophage of a lysogenic system is relatively less voracious than the bacteriophage of an ordinary system. The two systems have, however, one common quality: after infection in the case of one, and induction in the case of the other, the synthesis of deoxyribonucleic acid is completely stopped. In view of the persistence of other syntheses in lysogenic bacteria this stoppage is very significant, but the mechanism by which it is brought about is at present completely unknown.

#### FACTORS AFFECTING SHOCK TREATMENT

Ultra-violet radiation having an intensity of 125 ergs per  $\text{mm}^2$  is sufficient to induce production of bacteriophages throughout a population of *B. megatherium* in process of exponential growth, in a yeast-extract medium. To produce the effect in a synthetic medium containing glucose as its only organic constituent, however, radiation having an intensity of 3000 ergs per  $\text{mm}^2$  is necessary. The addition of various amino-acids to the synthetic medium increases the sensitivity to radiation. If the bacteria have been starved of organic food, the effect cannot be induced at all. Thus the bacteria can exist in either a sensitive or an insensitive state, or in a whole series of intermediate states.

According to their physiological state bacteria will or will not react to irradiation by production of bacteriophage particles. For bacteriophage production it is not, however, sufficient that adapted bacteria are irradiated [5]. Adapted bacteria irradiated in a yeast-extract medium produce bacteriophages and lyse if maintained in the same medium, but develop normally if they are at once transferred to peptone broth. Simi-

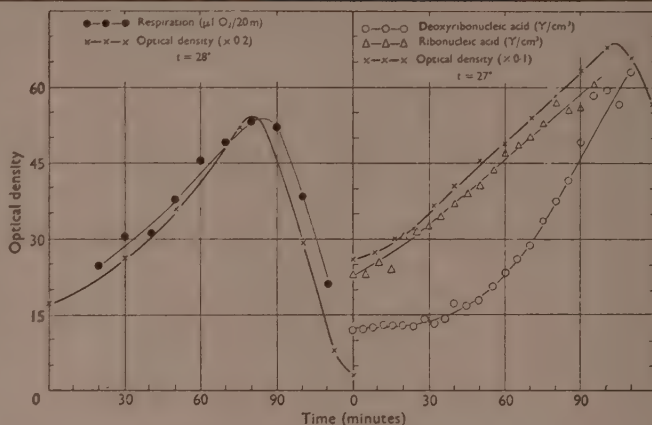


FIGURE 2 — Effect of irradiating a culture of *B. megatherium*. The time is measured from the cessation of irradiation. Note that the optical density and the respiration (left) are parallel, and keep step with the ribonucleic acid content (right). Note also that, at  $27^\circ\text{C}$ , the content of deoxyribonucleic acid stays almost constant for thirty minutes after irradiation.

larly, if they are starved of organic material for three hours after being irradiated, and nutritive substances are then made available to them, they again develop normally, just as though no irradiation had taken place. Thus under certain conditions a change of medium or an enforced fast can suppress the effect of irradiation. Furthermore, certain radiations in the visible spectrum suppress the effects of X-rays and ultra-violet light.

Rather complex conditions are therefore necessary if bacteria are to respond to irradiation by producing bacteriophages. These conditions clearly depend upon the metabolism of the bacteria both before and after irradiation.

#### CHEMICAL INDUCERS

What is the mechanism by which irradiation initiates production of bacteriophages? The most attractive hypothesis was that it acts by modifying the bacterial metabolism. It is known that in the rat the lethal effects of X-rays are suppressed by cysteine or thiomalic acid, which act as reducing agents capable of destroying the peroxide produced by the radiation. This observation poses the questions whether the effect of X-rays or ultra-violet light on *B. megatherium* is linked with similar oxidations, and whether reducing agents suppress the effect. It was in consequence necessary to examine the effect of reducing agents, at various concentrations, on normal bacteria.

Bacteria were inoculated into yeast-extract media containing varying amounts of sodium thiomalate. In some of the tubes, growth continued at a reduced rate for forty-five minutes; twenty



minutes later the bacteria had disappeared. Titration showed the presence of about two hundred bacteriophage particles for every bacterium which had disappeared. Thus thiomalic acid, in the complete absence of irradiation, induces bacteriophage production [6]; it follows that it will not suppress the inductive effect of radiation.

The action of thiomalic acid is not specific; thioglycollic acid, reduced glutathion, and *l*-ascorbic acid exercise the same effect. Malic acid and oxidized glutathion are inactive. The inductive effect is clearly not linked specifically with the presence of thiol groups, but rather with reducing properties in general.

#### FACTORS AFFECTING CHEMICAL INDUCTION

It is wrong to attribute to reducing agents an absolute power of inducing bacteriophage formation. The power of thiomalic acid in this respect is exercised only in certain media. There is no inductive activity in synthetic media, or in broth and a number of peptone preparations. Furthermore, not all extracts of bakers' yeast serve the purpose; this explains the negative results of the first attempts to induce bacteriophage production by means of reducing agents. All extracts, however, produce the effect on ageing. Under certain

conditions, mixtures of histamine and thiomalic acid are active, but neither of these substances alone has an effect. The problem is clearly a very complicated one. The identification of the chemical factors has only just been started, and knowledge of the mechanism of their action is still rudimentary.

#### DISCUSSION AND CONCLUSIONS

The conclusions reached in the following paragraphs must be treated with reserve, for in their formulation one is advancing from the solid ground of fact to the hazards of speculation.

Within lysogenic bacteria there exist one or several specific particles endowed with a genetic continuity; their number and nature may be ignored. According to modern beliefs they may be regarded as consisting essentially of molecules of deoxyribonucleic acid. These particles, the probacteriophages, multiply without recognizable effect upon the bacteria. The association between bacteria and probacteriophage is an enduring one; it may have originated many millions of years ago.

What is the origin and significance of probacteriophage? It seems to us to be, in the development of the bacteriophage, ontogenetically primitive. The belief that it is a phylogenetically primitive form of bacteriophage is tempting. If this hypothesis is correct the probacteriophage, being non-infective, can have been born only within the bacterium itself, as a result of the mutation of certain plasmagenes. If the hypothesis is incorrect, the probacteriophage is phylogenetically secondary, and derived from a bacteriophage. But what was then the origin of the bacteriophage? Supposing that it originated in a bacillus other than *B. megatherium*, we revert to the first hypothesis. The supposition that it originated from an organism parasitic on *B. megatherium* seems very improbable, because, apart from bacteriophage itself, no parasites of bacteria are known. Our inclination is thus to the first hypothesis, according to which the probacteriophage is a mutated plasmogene. It would thus be, phylogenetically, an endogenous particle.

In an artificially lysogenic strain, obtained by infecting bacteria and selecting the resistant organisms, the probacteriophage is extrinsic in the sense of having come from the outside. It is, nevertheless, endogenous rather than exogenous, since the bacteriophage from which it came was formed within a bacterium. This is a distinction which must not be overlooked.

Is the probacteriophage a virus? It is a particle possessing genetic continuity, which can multiply

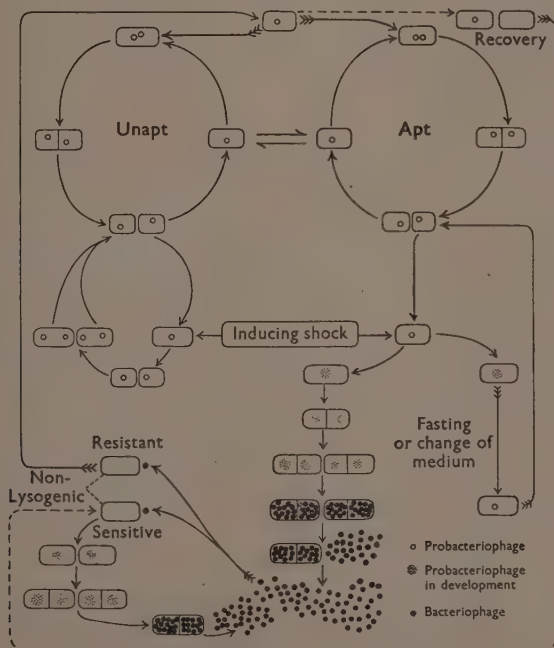


FIGURE 3—Probacteriophage/bacteriophage cycle in *B. megatherium*. For the sake of clarity only one probacteriophage has been represented per bacterium. (After Lwoff, Siminovitch, and Kjeldgaard.)

only within a specific bacterium, but which is neither pathogenic nor infective. It behaves as a normal particle, but can under certain conditions develop into a virus. It is thus the germ of a virus. It does not possess, unless latently or potentially, any of the major attributes of a virus. It is, however, very close to the latter, since it easily transforms itself into bacteriophage. It is a border-line virus and may be considered as the non-virus phase of the cycle of either a plasmogene or a virus.

A lysogenic system is in unstable equilibrium, but the stability varies from one lysogenic species to another and from one strain to another. Although only roughly sketched, the comparative physiology of lysogenic systems has already furnished results which it would take too long to discuss here. Lysogenic systems are very numerous, and probably represent the primary way in which bacteriophages are perpetuated. The factors which control the equilibrium of different lysogenic species and strains appear to be very variable. Whatever they are, the results of studies of *B. megatherium* (figure 3) represent a model of a lysogenic system.

The most important and difficult problem posed by lysogenic systems is that of the mechanism of action of the inducing agents. Discussion is simple because we know nothing whatever of the structures of the large molecules involved, or the factors which govern their specificity, or the mechanism of their biosynthesis. It is, however, almost impossible to avoid the conclusion that the synthesis of each of these molecules represents a series of specific reactions in which specific substances must necessarily take part, themselves formed and mobilized by other molecules with specific activities.

It can be considered that irradiation or reducing agents modify the bacterial metabolism in such a way that a substance which was not present beforehand is synthesized, or becomes available as a result of a disturbance in the normal metabolism. This hypothetical substance is the specific agent which induces or initiates the reaction (or reactions) corresponding to the change from probacteriophage to bacteriophage, just as in enzymatic adaption a galactoside molecule induces

the change from precursor to  $\beta$ -galactosidase [7]. There are, nevertheless, lysogenic strains which resist induction, and among them the spontaneous production of bacteriophages cannot be increased. It is, however, permissible to imagine that bacteria producing bacteriophages are mutants, the mutation governing the synthesis of a substance which is the specific inductor, or which can be transformed by the bacteria into an inductor.

However closely these hypotheses correspond with reality, one fact remains for final examination: that in lysogenic systems the transformation of probacteriophage to bacteriophage is governed by external factors.

The problems posed by the existence of different phases in the life histories of viruses are not peculiar to bacteriophages. Many viruses parasitic on animals exist also in non-infective states. It is known, too, that the virus of Shope's papilloma can multiply in a so-called 'masqued' form [8]. Knowledge of the substances which determine the different phases in the life cycles of viruses is important, not only from the theoretical but from the practical point of view. It paves the way for a study of the antagonists of inducing agents.

The fact that a metabolic change can induce a non-pathogenic particle to become lethal leads to the question of the mode of action of certain antibiotics. These may have, apart from their activity against other species, a physiological significance for the organisms that produce them. It is not possible *a priori* to reject the suggestion that some antibiotics initiate the synthesis of certain specific proteins. We may also ask whether they do not act on sensitive bacteria by inducing excessive or abnormal development of a particle, a development which could be pathogenic just as is the transformation of probacteriophage into bacteriophage. We can, in any event, maintain that it is today possible, with the aid of physical or chemical inducing agents, to cause a bacterium to transform an innocuous particle into a virus, and that the nature of the factors governing this transformation of a particle—or, if it is preferred, the development of a virus—is susceptible of experimental investigation.

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# Recent biological investigations in the Red Sea

N. B. MARSHALL

The unusual physical and biological conditions existing in the waters of the Red Sea give the marine biologist exceptional opportunities for research. The great excess of evaporation over precipitation gives rise to a high salinity; there are marked seasonal changes in surface temperature and direction of current flow; and unusually high temperatures exist at great depths. One consequence of such factors is that certain comparatively small and sedentary species may have been sufficiently isolated to evolve into peculiar and very distinct forms.

To the marine biologist with an interest in zoogeography, the Red Sea is a part of the complex of tropical faunal regions which stretches eastwards from the north-western Indian Ocean to the outermost islands of Polynesia in the Pacific. The physical oceanographer can more precisely define the Red Sea as a nearly closed basin with outflow across the sill, while the submarine geologist can trace its relationships to the Rift Valley system and the floor of the Indian Ocean. These are some of the aspects of oceanography which must be considered in any attempt to understand the evolutionary history of its fish fauna. That such an attempt can now be made is largely due to Major H. W. Hall, M.C., who since 1947 has generously and frequently placed his motor yacht *Manihine* at the disposal of the British Museum (Natural History) for the purpose of marine investigations. The writer has already given a brief outline of this work [1].

The choice of the Red Sea for biological surveys was readily decided. The earlier work of such vessels as the *Pola* (1897), the *Ammiraglio Magnaghi* (1923-4), and the *Mahabiss* (the John Murray Expedition, 1933-4), had been mainly hydrological, and from the biological aspect the Red Sea had by no means been well explored. For example, the only comprehensive work on the fish fauna is that of Klunzinger [2] dated 1870-1.

The *Manihine* has now undertaken two biological surveys in the Red Sea, the first being of the Gulf of Aqaba during the winter of 1948-9, when hydrological observations also were made, and the second of the Sudanese Red Sea during the winter of 1950-1. On both surveys the writer had the pleasure of working with Major Hall and his skipper, Thomas Hargreaves, not only in collecting the marine fauna, but in making field observations, which are becoming more and more

essential to an understanding of the nature of animal species. The time is not far distant when they will be indispensable.

This is not the occasion on which to consider how one sets about collecting marine organisms in an area with extensive coral reefs, but it must be said that methods of collection which are suitable in the North Sea are rarely suitable in the Red Sea. The trawl and dredge must be used with much circumspection, otherwise they may soon be torn to shreds on the jagged coral masses, and, even when they are worked over a coral-free bottom, the catches give a limited picture of the invertebrate and fish fauna. The greater part of this fauna appears to be associated with coral formations and seems to be dependent on them, either directly or indirectly. In turn, reef corals grow vigorously, as Yonge [3] has remarked, only in well-illuminated waters, being mainly confined to those less than 50 metres in depth. Even in the shallows, growth is poor if the water is at all turbid. The Arab and Sudanese fishermen are well aware of the association between coral and the fishes, and say emphatically 'No stone, no fish.'

The reports on the survey of the Gulf of Aqaba are now in the press, and work on the fish collections from Sudanese waters is sufficiently advanced for a discussion of the evolutionary history of the fish fauna. It would, however, be unwise and unscientific to try to draw firm conclusions at present.

The geological history must first be considered, and it may be said at once that the Red Sea is a relatively young sea, as measured by geological time. Apparently the original Red Sea came into being as the result of faulting of Eocene strata, and the filling of this great rift with water from the part of the Tethys Sea to the north of it. Later, the connection with the Tethys Sea seems to have been lost, for, most probably during Miocene

times, it was subject to intensive evaporation, giving rise to great deposits of rock salt. Almost certainly this change to hypersaline conditions must have killed off the whole, or by far the greater part, of the marine fauna. The connection between the Red Sea and the Indian Ocean is believed to have been established during the latter half of the Pliocene period: it was during this time that there must have been invasions of Indian Ocean fishes into the Red Sea.

This is the generally accepted geological history of the Red Sea, but there is a further possibility. Sewell [4] has suggested that the drop in the ocean levels, which resulted from the formation of the Pleistocene ice caps, may have been sufficient to leave the shallow sill at the southern end of the Red Sea uncovered (today its maximum depth is about 100 metres). Sewell concludes that this emergence of the sill must have converted the Red Sea into an inland salt lake, and that, owing to the great excess of evaporation over precipitation, the waters became extremely salty, once again leading to the mass-extinction of the marine fauna. Later the sea-level rose as the ice caps receded towards the end of the Glacial period, and once more the Red Sea became connected with the Indian Ocean, resulting in a second and final influx of fishes from the latter waters.

Against this geological background the biological facts may now be reviewed. Of the 113 species of fishes which were collected in the Gulf of Aqaba, about 15 per cent. proved to be species that have not so far been found outside the Red Sea. Well over double this number of species have been taken in Sudanese waters, and about 80 of them have been examined. Of these 80, six prove to be new species, and five are known species which again appear to be limited to the Red Sea. While the proviso must be made that certain of these peculiar species may eventually be found elsewhere, it is likely that at least 15 per cent. of them are confined to the Red Sea. Moreover, it is particularly interesting that ichthyologists are beginning to find that earlier workers on the fishes of the Indian and Pacific Oceans have sometimes confused quite distinct Indo-Pacific species or 'forms' with species which were first described from Red Sea collections. Many fishes which were once regarded as identical have now been shown to belong to a complex of separate species. This is perhaps only to be expected from the closer attention now given to morphological features and the intelligent use of basic colour patterns, together with field observations. It is reasonable to con-

clude that not only is the distribution of the fish fauna of the Red Sea of more than ordinary interest, but to predict that further study will reveal the Sea as much more than a marine pocket of the Indian Ocean containing an extension of the Indo-Pacific fish fauna.

We do not know yet the number of fish species which are common to the Red Sea, the Indian Ocean, and the Pacific Ocean, simply because the old concept of morphological species is only just beginning to be replaced by the concept of biological species. However, it is not the present intention to discuss this point, but rather to concentrate on how the species which are peculiar to the Red Sea may have arisen.

There are certainly two possibilities. On the one hand, they may have evolved from species which entered the Red Sea from the Indian Ocean; on the other, they may be no more than relics of species which were once common to these two marine areas.

Beginning with the latter suggestion, it seems unlikely that a fairly high number of species, which are locally confined today, should all have possessed the potentialities of surviving in the Red Sea while the Indian Ocean ancestral stock perished. After the connection between the Red Sea and the Indian Ocean had been established during Pliocene times, the waters which flowed in must have been subject to certain physico-chemical changes. Gradually, the main hydrological features which now distinguish the Red Sea from the Indian Ocean would have evolved; they are higher summer temperatures, isothermal conditions, and distinctly higher salinities. It may be argued that such changes would have tended to bring about the extinction of those species which were closely adapted to conditions in the Indian Ocean rather than to favour their continued existence. To put it another way, it seems unlikely that these invading species should have all been pre-adapted to conditions in the Red Sea. It is not suggested that there are no relict species in the Red Sea today, but that all the locally confined species belong to this category seems highly improbable.

If certain species have evolved within the Red Sea, this almost certainly implies that they became isolated from the Indian Ocean ancestral stock. Mayr [5] has given a lucid analysis of the relationships between isolation and the formation of new species or subspecies, and has shown that isolating factors are undoubtedly linked with evolutionary change. This is not to imply that an isolated part





FIGURE 1 — *The M/Y Manihine at Aqaba.*



FIGURE 2 — *Fishes caught by trolling off the edge of coral reefs. The three uppermost are specimens of *Caranx sexfasciatus*; following these are a barracoua (*Sphyraena picuda*) and two groupers (the lowermost is *Variola louti*). (The top fish is about 3 ft long.)*

FIGURE 3 — *Redwan, the head fisherman of Aqaba, throwing a cast-net. This method of catching fish is widespread in tropical and subtropical parts of the world.*





FIGURE 4 - A grouper (*Epinephelus fuscoguttatus*) caught by hand-line close to a coral patch.

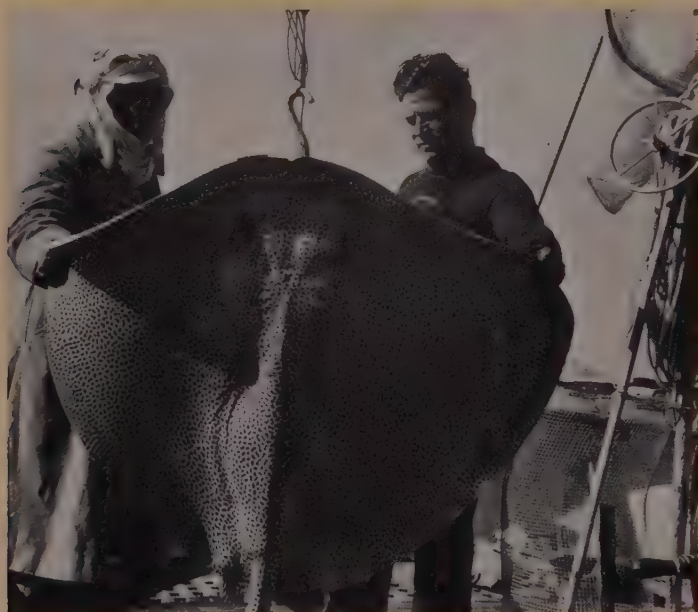


FIGURE 5 - A large specimen, about 4 ft wide, of a stingray (*Dasyatis uarnak*).

FIGURE 6 - The larger predacious fishes lurk off the edge of coral reefs. The two in the foreground are kingfish (*Scomberomorus commerson*), while just above them is a barracoua (*Sphyraena picuda*). (The nearest fish is about 3 ft 6 in long.)

(Photographs by Major H. W. Hall)





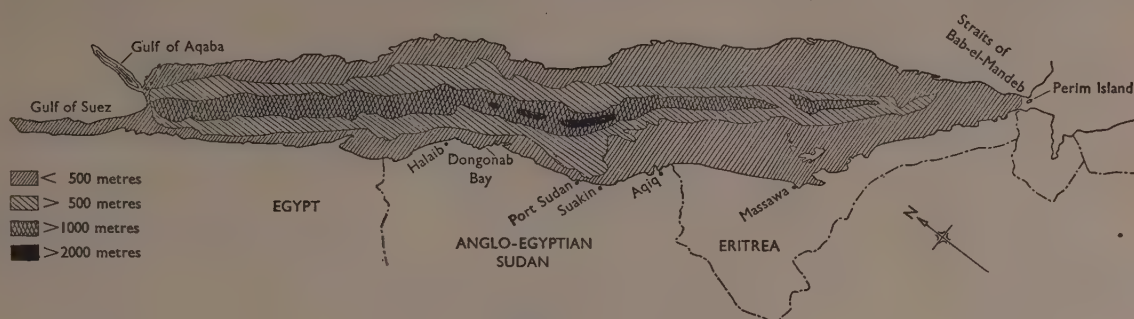


FIGURE 7 - Bathymetric chart of the Red Sea.

of a species is bound to evolve away from the parent stock, but to say that it does happen in certain instances. Why one species should be stable while another may undergo rapid change is still largely a mystery.

The Red Sea is a long deep basin, with a maximum depth of about 2000 metres, connected to the Gulf of Aden through the narrow straits of Bab-el-Mandeb. Just inside these straits the sea floor rises up to form a sill, having a maximum depth of about 100 metres (see figures 7 and 8). The sill is hardly likely to be a barrier to the ingress of fish, but its influence on the general hydrology of the Red Sea may be important.

The Red Sea is set in a hot, arid area with north-north-west winds prevailing from May to September, while south of latitude  $22^{\circ}$  N south-south-east winds blow from October to April. These physical features mainly determine the hydrology. Owing to the fact that evaporation greatly exceeds precipitation, the salinity is high, reaching about 4.1 per cent. in the northern Red Sea, while surface temperatures may exceed  $30^{\circ}$  C in summer. In winter, however, the surface waters of the northern Red Sea may be cooled to as low as  $18^{\circ}$  C. Moreover, this marked winter cooling, coupled with intense evaporation, causes the formation of deep water (filling the Red Sea basin below the depth of the sill) with a salinity of about 4.1 per cent. and a temperature between  $21.5$  and  $22^{\circ}$  C. The great differences between the sub-surface temperatures of the Red Sea and the Indian Ocean may be seen from the following table, which is taken from Ekman [6].

Lastly, owing to the prevailing winds, surface currents flow into the Red Sea from November to March, and outwards to the Gulf of Aden from June to September.

Returning to consider possible isolating factors, it may be said that at the entrance to the Red Sea from the Gulf of Aden the salinity rises from about

3.6 per cent. to 3.8 per cent., gradually increasing northwards to 4.1 per cent. (see figure 8). Surface temperatures may rise even more abruptly, as may be seen by comparing those occurring off Perim Island, just south of the ridge, with those of southern Red Sea waters.<sup>1</sup> From January until June these waters are warmer than those off Perim Island by  $0.5$ – $2.7^{\circ}$  C, and from July to September the differences amount to 6 or  $7^{\circ}$  C; they diminish to about  $1$ – $3^{\circ}$  C from October to December. Experiments have shown that fish are able to detect a difference of temperature of as little as  $0.2^{\circ}$  C, and there is abundant evidence that changes in sea temperatures in time and space may have marked effects on fish movements and may rigidly determine the limits of distribution.

Whether the differences between the water masses of the Red Sea and the Gulf of Aden do actually limit exchanges between certain of the fish populations is not at present known. It could be ascertained only by a close study of the two faunas. However, there are great deposits of pteropod shells on the sea floor inside the sill, and Stubbings [7] has suggested that, on being carried

Depth (metres)	Temperatures ( $^{\circ}$ C)	
	Red Sea	Indian Ocean (Maldives area)
0	25–29	28–29
200	21–25	13–15
400	21–22	10.2–11
600	21.4–21.8	9
800	21.5	7.5–8
1000	21.5	6–7
1500	21.5	4
2000	21.5	2.5–3

<sup>1</sup> I am indebted to Lt.-Col. R. B. Seymour Sewell for allowing me to make use of temperature data in his possession.

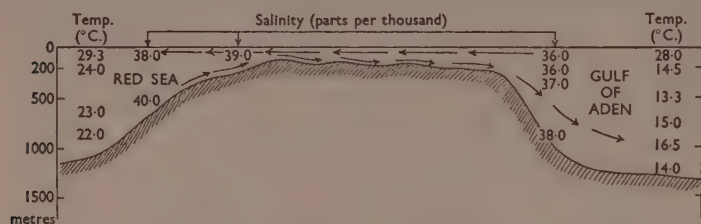


FIGURE 8 — A section through the sill at the southern end of the Red Sea, showing the differences in temperature and salinity on either side. Note also the inflowing surface current (November to March) and the deeper outflowing current. (After SCHOTT, G. *Geographie des Indischen und Stillen Ozeans*. Hamburg, 1935.)

into the Red Sea, these planktonic molluscs are killed when they meet the warmer and more saline waters, the shells then sinking to form sea-floor deposits. Sewell [4] has remarked that many of the free swimming planktonic copepods widely distributed in the Indo-Pacific area were unable to establish themselves in the Red Sea owing to the quite sudden changes in temperature and salinity. What seems to be true of these organisms may prove true of fishes.

Temperature has a further effect, namely on the spawning seasons of fishes, for it seems that whatever else may be their requirements, many species liberate their eggs and sperm only within narrow ranges of water temperatures. If a certain species has different spawning seasons in the Red Sea and the Gulf of Aden, there will be no genetic interchange between the two populations and over a period of time the two gene complexes might diverge in isolation. The *Manihine* collections have shown that many species of Red Sea fishes spawn during the winter, but little seems to be known of the conditions in the Gulf of Aden. More data are plainly needed.

It seems safe to conclude that physical differences between the water masses of the Gulf of Aden and of the Red Sea could be a barrier to

genetic interchange, directly or indirectly. Lastly, it may be mentioned that the habits of the fishes themselves may be another factor, the smaller species, which are closely dependent on coral life and relatively sedentary, being more prone to evolutionary change than the larger and faster-swimming pelagic or bottom-living fishes.

These and similar problems can be solved only by continued study of the biology and physical oceanography of marine basins. There is

little doubt that many basins harbour a fairly high proportion of locally confined species. For example, the Gulf of California contains certain deep-sea fishes which have never been taken elsewhere, and the same is true of some of the species of penaeid prawns and sea anemones and of the floating *Sargassum* weed. The Sulu Sea, a partly enclosed basin to the north-east of Borneo and west of Mindanao, has remarkable hydrological features and contains many species of macrurid fishes never trawled elsewhere. Hubbs [8] has observed that 'these waters of unusually high temperatures at great depths contain a large proportion of peculiar and very distinct species, which have probably been evolved in this region of peculiar environmental conditions. The process of their evolution has doubtless been aided or hastened by their isolation, more or less complete, in this partly inclosed sea.' It will be interesting to see if the catches of the Danish research vessel *Galathea*, now working in this area, change these conceptions. The study of evolution on land and in freshwater lakes is well advanced, but we still know little of how new species come into being in the sea. Further oceanographical work on marine basins should do much to increase our understanding, whatever the final answers may be.

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# Interference filters in optics

K. M. GREENLAND

Optical filters, owing their properties of selective transmission and reflection to wave-interference, are beginning to find applications in academic and technological research and in industrial instruments. Interference filters of one type are used, for example in flame photometry and astronomy, for selecting single lines from line spectra, while in high-intensity projection systems filters of a different type can deflect heat radiation from the light beam.

## GENERAL PRINCIPLES

The intensity and colour of light transmitted or reflected by an interference filter depends primarily on the result of wave interference induced in the filter itself. It happens that the first interference filter to be so called had very distinctive properties, which it owed to a combination of thin metal and dielectric films; consequently, the name is often used to denote that particular type of filter. Nevertheless, the term is now sometimes applied, with scientific propriety, to many other filters, and is given its broader meaning in this article. I propose to use the name Fabry-Pérot for the metal-dielectric type. It is hoped that this name, which is already in use, will be generally accepted; it is appropriate in that the optical system of the filter is similar to that of the Fabry-Pérot interferometer.

All interference filters (except the Lyot birefringence filter) consist of a pile of thin films deposited on a supporting surface, usually of glass. Any absorption of light by the films plays no constructive part in the action of these filters. The films serve only to provide partially reflecting surfaces separated by the proper distances—the interfering wave systems set up by multiple reflections between these surfaces determine the optical properties of the filters. In the Lyot filter, interference is induced by birefringent crystals and polarizers.

Short of putting into words Maxwell's equations for electromagnetic radiations, it is impossible to describe interference in thin films on a satisfactory physical, rather than conventional, basis. It is perhaps sufficient to say that the radiation reflected back from each surface of a single film to the opposite surface alters the transmission factor of that surface, to an extent determined by the phase retardation of the reflected wave-train. This retardation is due to the double transit across the film, and to phase changes on reflection. The

transmission factor of a set of interference films thus depends on the relative phase retardations caused by each film. The property of colour discrimination is inherent in all interference filters, because the phase retardation is mainly determined by the ratio of film thickness to wavelength.

The component films may be of transparent materials of differing refractive indices; in these all-dielectric filters each film boundary reflects, because of the discontinuity in refractive index at the boundary. Semi-transparent metal films separated by transparent dielectric films are used when more highly reflecting boundaries are required, and when the loss of light by absorption in the metal can be tolerated. As a general rule, the simpler combinations of transparent films give spectral transmission curves with broad maxima and minima, but a greater number of films, or more highly reflecting surfaces, increase the dependence of transmission on wavelength by intensifying the interference system, and so make the filter more selective.

The substance of the films, their number, order of deposition, and thicknesses, thus determine the shape of the spectral transmission curve, and its position in the wavelength scale.

The film materials must of course be amenable to deposition in a controllable manner. The almost universal method of deposition is by volatilization in a high vacuum: a wide range of substances can be deposited by this method in films of extremely uniform thickness [1-4]. If a suitable material is heated to its evaporation temperature in an evacuated space (pressure less than  $10^{-6}$  mm of Hg), it is volatilized and projected through the space with almost no diffusion. It condenses on any cool surface which it reaches, and forms a film which is as uniform in thickness as the geometry of surface and evaporator allows. Deposition to the correct thickness is essential. For transparent films, the interference colour seen by

reflection may be used as a gauge, since it is sensitively related to the thickness, but metal films must be monitored photometrically or electrically.

#### CALCULATION OF FILTER CHARACTERISTICS

The optics of single thin films are dealt with in the standard works on optics under the heading 'colours of thin films,' but the classical mathematical treatment becomes hopelessly unwieldy when applied to multi-layer films.

Great advances have recently been made in the methods of calculating transmission and reflection factors for multi-layer filters, and particularly in the derivation of general expressions for any number of layers. A review of modern methods is given by Abelès [5]. The starting point may be an application of Maxwell's electromagnetic field equations [6-8], or the derivation of a recurrence formula from the expression for the summation of the multiple reflections within a single layer [9, 10]. A third basis of calculation is through the analogy of electrical and optical impedance [11]. These are all rigorous methods, but often a precise expression for the transmission curve is unnecessary (and is indeed not justified if the optical constants of the films are not accurately known). For approximate calculations, a graphical method such as that perfected by Cotton [12] is adequate.

#### ALL-DIELECTRIC FILTERS AND BEAM-SPLITTERS

Transmission interference filters are, in effect, beam-splitters: they reflect as well as transmit. The filters which have no metal films reflect all the radiation in their working range which is not transmitted. If the filter is noticeably colour-selective, and the incident beam white, the colours of the reflected and transmitted beams will be truly complementary. This may be prettily demonstrated by deflecting the two beams on to a white screen so that they illuminate overlapping areas: the overlapping colours recombine to give white again.

A film of zinc sulphide deposited on glass, and having an optical thickness (geometrical thickness  $\times$  refractive index) equal to one-quarter of the typical wavelength of yellow-green light, has a reflectivity of 30 per cent. and a transmission of 70 per cent. for white light [13, 14]. Although the high reflectivity of this so-called quarter-wave film is due to a maximum interference effect, it is a broad maximum in terms of wavelength, so that

coloration of the reflected and transmitted beams is hardly noticeable to the eye: the film is practically a neutral filter (figure 1). As a beam-splitter, the high-index quarter-wave film is found in the vertical illuminator of metallurgical microscopes [15]. (The quarter-wave film of low refractive index is the common anti-reflection film.)

The next stage of advance is reached by constructing multi-layer films of materials of alternately high and low refractive index, e.g. zinc sulphide and magnesium fluoride. For instance, a three- or four-layer beam-splitter gives high reflectivity at a chosen wavelength (figure 2), or transmitted and reflected beams of complementary colours (figure 3) [14, 16].

As the number of layers is increased, a wide variety of transmission characteristics naturally becomes possible, ranging from filters with sharp cuts to neutral filters which transmit and reflect beams of equal intensity without loss of light. The neutral filters are now being produced commercially; an arrangement of films resulting in a close approach to the symmetrical beam-splitter is shown in figure 4. A disadvantage of this device is that the transmitted and reflected beams are partially polarized. In fact, a completely polarizing filter may be made in this way [16, 17].

A recent advance in non-absorbing filters is the designing of filters which transmit white light but reflect heat. These filters have the advantage over heat-absorbing filters that the filter itself does not get very hot; the heat is returned to its source, or directed out of the optical system by the back door. Separation of heat and light is not complete, but while only 10-15 per cent. of light is lost by reflection, the transmission of heat radiation at 10,000Å may be less than 20 per cent. At longer wavelengths, the transmission rises again, but in the high-efficiency sources, such as projection arc lamps, with which these filters will be most useful, most of the heat energy is carried by the near infra-red radiations. These heat-reflecting filters are a commercial product, but the present writer has not seen any published formulae for their construction. Figure 5 shows the construction and measured transmission curve of a filter which goes some way towards achieving the desired result.

#### FABRY-PÉROT FILTERS

The first published accounts of the Fabry-Pérot filter are those describing the filters invented by W. Geffcken of the firm of Shott, at Jena [18, 19]. The construction of this filter is simple: it is a sandwich made of a film of transparent dielectric



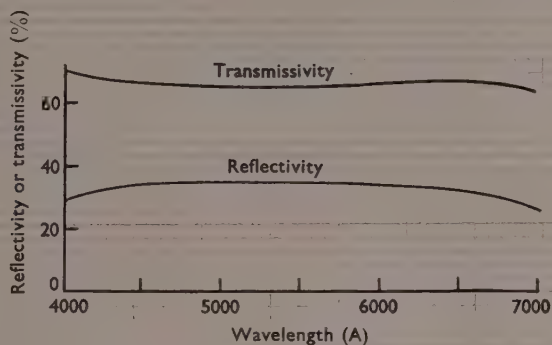


FIGURE 1 - Neutral filter.

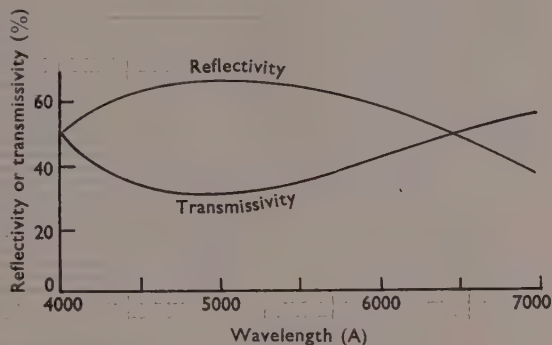


FIGURE 2 - High-reflection beam-splitter.

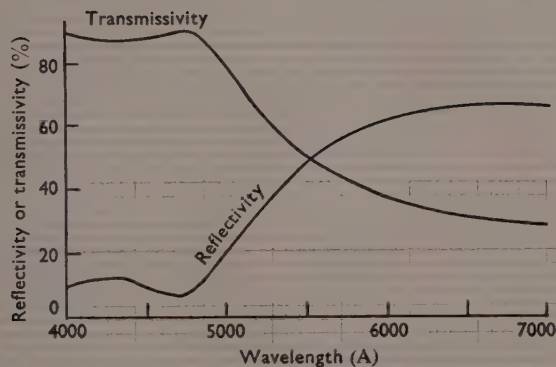


FIGURE 3 - Colour filter.

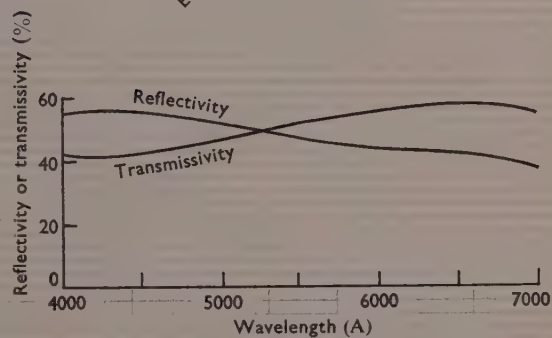
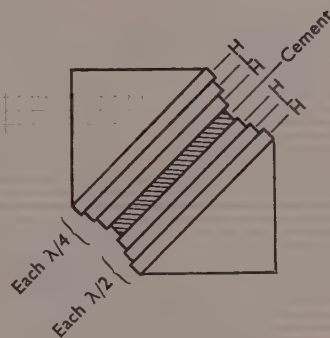


FIGURE 4 - Beam-splitter.

H Indicates film of high refractive index.

L Indicates film of low refractive index.

$\lambda$ ,  $\lambda/2$ ,  $\lambda/4$  indicate optical thickness of film ( $\lambda = 5500 \text{ Å}$  approx.).

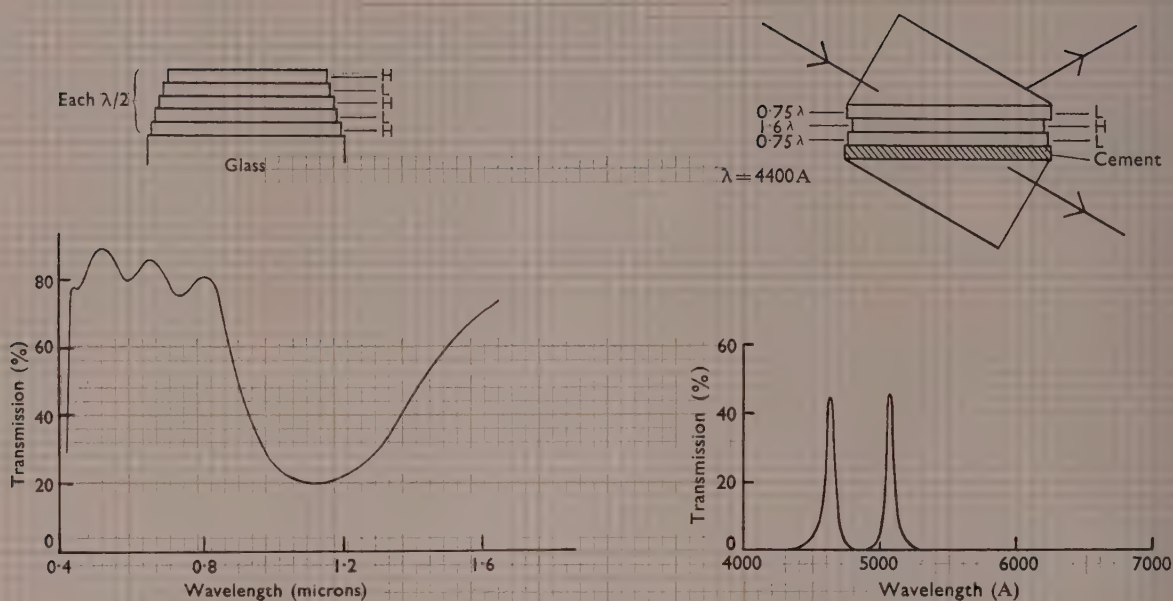


FIGURE 5 - Heat-reflecting filter.

FIGURE 6 - Turner filter.

(By courtesy of the Journal de Physique.)

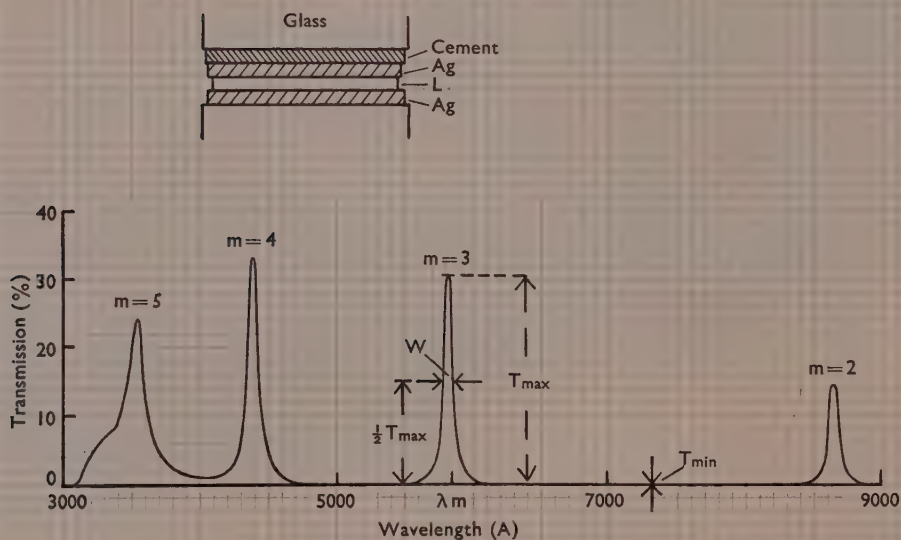


FIGURE 7 - Fabry-Pérot filter.



between two semi-transparent silver films. The films are deposited on a glass support, and are protected by a coverglass.

The expression for the transmission of light by these filters is the same as for a Fabry-Pérot interferometer [6]; this is not surprising, because the filter is in principle a Fabry-Pérot *étalon* of very low order, in which the quartz spacers are replaced by a solid transparent film occupying the whole space between the silvered plates.

The characteristics of the filter are illustrated by figure 7, which is based on a measured transmission curve. The table gives the actual values of these characteristics for the particular filter measured. The band width at one-tenth of the peak transmission may be taken as three times the half-width ( $W$ ) of the band.

Order of band .. .. . $m$	2	3	4	5
Wavelength of centre of band .. $\lambda_m$	8645 Å	5794 Å	4393 Å	3543 Å
Half-width of band .. .. $W$	75 Å	62 Å	77 Å	177 Å
Peak transmission of band .. $T_{max}$	14.5 per cent.	30.2 per cent.	33.5 per cent.	24.3 per cent.
Minimum transmission between bands $T_{min}$	0.03 per cent.	0.15 per cent.	1.2 per cent.	

The Fabry-Pérot filter has, in general, a number of transmission bands distinguished by their orders of interference (consecutive integers, usually up to not more than 4 in the visible region of the spectrum). The mean wavelengths ( $\lambda_m$ ) and orders ( $m$ ) of these bands are determined by the optical thickness ( $\Delta$ ) of the transparent spacer film, the relation being

$$\lambda_m = 2\pi\Delta \cos \theta / (m\pi - \phi),$$

where  $\theta$  is the angle of refraction in the spacer film and  $\phi$  represents phase shifts due to reflection by the silver films. The correct adjustment of the spacer film is clearly an essential feature in the construction of these filters: two recently published methods enable the adjustment to be made with high accuracy during the deposition *in vacuo* [20, 21].

A transmission band centred on a particular wavelength may be of any chosen order; the half-width of the band and the wavelength separation between neighbouring bands both decrease with increasing order, but the peak transmission is un-

affected. If the first-order band is placed anywhere in the visible spectrum, by proper choice of the dielectric film thickness, the second-order band is in the ultra-violet, but a second-order band in the red or yellow region allows a third-order band to intrude in the blue or violet. Unwanted transmission bands can usually be cut out with a glass filter, a dye filter, or an interference filter of lower order.

The peak transmission of a band, and the intensity of the continuous background transmission, are controlled by the thickness of the silver films. A compromise must be made between these values, because raising the peak transmission by using thinner silver films leads to a higher background transmission: indeed, the contrast  $T_{max}/T_{min}$  is reduced. The half-width also increases with in-

creasing peak transmissions. The useful range of peak transmissions is from 10 per cent. to 40 per cent.; the half-widths are then between 50 Å and 300 Å, according to the order of interference and the position in the spectrum. The minimum transmission, at a wavelength roughly midway between peaks, may be less than 0.25 per cent. for

a peak transmission of 30 per cent., but it must be remembered that in some applications the whole background transmission is integrated—as it would be, for instance, by a photocell.

A striking property of Fabry-Pérot filters remains to be mentioned: this is the dependence of the wavelength of each transmission band on the angle of incidence of light on the filter. It is possible to tune the filter over a range of about 20 Å by tilting it, but beyond this range the band splits into two polarized components. It also follows, unfortunately, that in a convergent or divergent beam the transmission band is broader. The effect of the angle of incidence is reduced by using a dielectric of high refractive index, such as zinc sulphide, for the spacing film, but a less refractive medium, e.g. magnesium fluoride, gives narrower transmission bands.

Absorption of light-energy in the silver film limits the efficiency of Fabry-Pérot filters. A most elegant way of preventing this loss has been proposed by Turner [22], and put into effect by himself, Billings [23], and others. In this filter (called by Turner the frustrated total reflection

filter) the metal films are replaced by transparent films of low refractive index in optical contact with the hypotenuse faces of two prisms (figure 6). The spacer film is of high refractive index. The essential feature of this filter is that the incident light falls on the films at an angle greater than the critical angle. Although the conditions hold for total internal reflection, a fraction of the incident light escapes through the films of low refractive index if they are thin enough. The interference system within the spacer film is thus similar to that in the Fabry-Pérot filter, but with the difference that no light is lost by absorption. The transmission bands are consequently much narrower than those of the Fabry-Pérot filter, but occur in polarized pairs. A beam of very small angular aperture is necessary if the narrow bandwidth is to be realized, because this filter is very sensitive to variation in angle of incidence.

Apart from the narrower bands, a great advantage of this filter is that its efficiency can be maintained in the ultra-violet and infra-red regions, where the metal reflectors of the Fabry-Pérot filter become very inefficient [24].

The Lyot birefringence filter is the most selective of all filters, and can be made to give a transmission band of 1 Å in width, but it is rare and expensive. Its description is beyond the scope of this article; a full account of recent forms of the filter has been given by Evans [25].

# REFLECTION FILTERS

A Fabry-Pérot filter is itself a mirror giving one or more dark bands in an otherwise continuous spectrum of reflected light. As a narrow-band absorption filter, it may be improved by making one metal film opaque [6]. If the other metal film is replaced by a multi-layer dielectric coating, a range of reflection characteristics, analogous to those of the all-dielectric filters but in a higher region of reflectivities, is possible. Enhanced reflection mirrors, consisting of silver films coated with two-layer dielectric films, have been reported to give reflectivities up to 99.5 per cent. [26, 27]. This system is also used with success in Fabry-Pérot filters to narrow the transmission bands.

# CONCLUSION

The practical possibilities of interference film combinations are not by any means limited to the filters which have been described here. Though a number of interesting combinations have been omitted on the grounds that, owing to the difficulty of reproducing them commercially, they are not likely to be immediately available, it is nevertheless certain that other useful filters will be evolved, now that the technique of applying the principles is well established. There is a growing number of investigators in the field, attracted perhaps by the peculiar elegance of this method of utilizing optical interference.

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# The industrial diamond

R. S. YOUNG

Scientists of all persuasions make direct or indirect use of diamond tools, and the following communication from the diamond research laboratory at Johannesburg should therefore be of general interest. The hardness of diamond results from its crystal packing—a fact intuitively perceived 2000 years ago by Titus Lucretius Carus, who wrote: 'Whatever seems to us hardened and closely set must consist of units more closely hooked and held, knit deeply together in branch-like shapes. Among the first in this class stand diamond stones.'

Although the use of a diamond to cut glass dates from antiquity, it is only in recent years that the demands in many spheres of technology for its unequalled hardness and resistance to abrasion have placed the industrial diamond in the front rank of the world's strategic minerals. To most people, the word diamond conjures up a vision of a sparkling gem, and perhaps few realize that 80 per cent. of the world's output is used for industrial purposes.

An industrial diamond is one which on account of imperfections such as inclusions, spots, cracks, coatings, inferior crystal form, or dark colour, cannot be economically cut and utilized as a gemstone. The size of the diamond, too, determines the category into which a stone is placed; an inclusion in a large diamond can often be removed and still leave a marketable gemstone, whereas a defect of the same size in a small diamond would render it unfit for jewelry purposes.

Diamonds, whether they be of the industrial or of the gem variety, are found in nature in two types of deposit:

- (a) Kimberlite or pipe formations, from which they are extracted by mining operations.
- (b) Alluvial deposits, where the diamonds occur in gravel beds along rivers or ocean terraces, and are recovered after removing the overburden by the techniques of strip-mining.

Much has been written about the genesis and occurrence of the diamond [7]. Though there are many conflicting views, probably most geologists incline to the belief that alluvial diamonds have been derived from the disintegration of kimberlite deposits and the subsequent transport of the diamonds by water. Kimberlite is an olivine-phlogopite rock containing crystals of olivine, enstatite, diopside, chrome-diopside, phlogopite, ilmenite, and garnet. It was probably produced from a residual magma remaining after the solidification of the rocks forming the peridotite shell now

underlying the Earth's crust. As the shell became cooler, the temperature of the magma fell to the point where it began to solidify, and during this period diamond and graphite separated from the magma and finally became incorporated in the ultra-basic rocks.

Over 97 per cent. of the world's diamonds are obtained from the continent of Africa: Angola, Belgian Congo, French Equatorial Africa, French West Africa, Gold Coast, Sierra Leone, South-West Africa, Tanganyika, and the Union of South Africa. Apart from Africa, the only significant producers are Brazil, British Guiana, and Venezuela. By far the largest single source of industrial diamonds at present is the Belgian Congo. Industrial and gem diamonds are found in the same deposits, but their ratios vary widely. For instance, some properties in South-West Africa yield over 95 per cent. gemstones, whereas the output of most of the mines in the Belgian Congo is over 95 per cent. of the industrial variety.

The extractive processes in diamond mining present several unique features. In the first place, the content of valuable constituent in the ore is extremely low, one part of diamond being found in 14 million parts of kimberlite. Secondly, a rapid increase in the value of a diamond occurs with increase in size, so that crushing and grinding operations must be kept to a minimum. Thirdly, owing to the high value of the product and the irregularity of occurrence in the feed to the plants, extractive processes must be designed to yield virtually complete recovery. Fourthly, the diamond industry cannot check its operations by chemical analysis of the incoming feed and outgoing tails, since there is as yet no way of chemically distinguishing the very small quantity of crystalline carbon from the relatively large amounts of other carbonaceous material in ore samples. Finally, the high melting-point of diamond, its inertness towards acids and alkalis, and the fact that it is

injured by heating at high temperatures, all preclude in diamond recovery the use of common processes such as roasting, smelting, or leaching.

The first step in the recovery treatment of diamondiferous ore is some form of gravity concentration, in which the very small quantity of diamond, with its specific gravity of 3.5, is separated, together with other heavy minerals, from the bulk of quartz and lighter silicates, which have a specific gravity of about 2.7. This gravity separation may be effected by washing pans, jigs, or heavy-media processes. In the case of diamonds from kimberlite deposits, the gravity-concentrate in the form of a thin suspension with water is passed over an inclined table coated with a thick layer of grease. The diamonds adhere to the grease, but rock particles are carried away by the stream of water. Most diamonds from alluvial deposits, however, do not adhere to grease, since, unlike diamonds from kimberlite, they are not water-repellent; the entire gravity-concentrate has to be hand-sorted to recover them. The hydrophilic nature of the surface of a diamond from alluvial deposits is due to the presence on its surface of a very thin but strongly adsorbed film of salts.

Two new processes to improve diamond recovery have lately been developed at the diamond research laboratory at Johannesburg, an institution recently established by the leading mining companies to serve producers and users of diamonds throughout the world [8]. One of these processes, based on electrostatic separation, is designed for the recovery of the smaller sizes of diamonds [4]. It depends on the fact that diamond is almost a non-conductor of electricity, whereas most gangue minerals are weakly conducting, and are deflected from a roll electrode in an electrostatic field when a stream of dry diamondiferous gravel is passed over it. The other process is one in which the diamondiferous alluvial gravels are treated with surface-active reagents, to impart a water-repellent film to the diamond but not to the silicate or rock particles [6]. When the diamond is thus rendered water-repellent, it will adhere to a grease surface in the same manner as diamonds from kimberlite deposits, which are naturally water-repellent. After this treatment, the diamondiferous gravel is passed over a rubber belt coated with grease, and a fresh grease surface is continuously exposed to the diamondiferous gravel by mechanically applying the grease at one end of the belt and scraping it off at the other. These processes have passed through the laboratory and pilot-plant stages, and are now being

installed on a large scale at several places in Africa.

The chemical properties of diamond differ in some respects from those of graphite. It is virtually unattacked by acids, singly or in combination, or by molten alkalis in the absence of oxidizing reagents. Diamond powder slowly burns in the air at temperatures above 500° C, and the extent of combustion depends on the temperature, length of heating, and particle size and type of diamond. The better grades of industrial diamond, like the gemstone, are practically pure carbon, but the lowest category, called boart, may contain several per cent of impurities.

The principal physical properties of the diamond which make it so valuable in industry are its great hardness and its resistance to abrasion. An examination of the physical and mechanical properties of natural and synthetic abrasives indicates that the diamond stands at the head of the list of these materials in melting-point, scratch and indentation hardness, resistance to wear, abrasive action, compressibility, modulus of elasticity, breaking load, and thermal conductivity.

Some very interesting work carried out recently at Oxford [1], on the thermal conductivity of alloys and non-metals at low temperatures, indicates that the thermal conductivities of all pure dielectric crystals have a general resemblance. The maximum value of the conductivity of diamond at low temperatures is of the same order of magnitude as that of copper and other good conductors.

The researches of Bowden and his associates at Cambridge on friction of metals have recently been extended to non-metals. It has been shown that the friction of clean diamond on diamond is high, and that the shear strength at the interface is comparable with the shear strength of single diamond [2]. Large-scale seizure does not occur, because the deformation of the diamond in the region of contact is elastic, and the real area of contact necessarily remains small.

Diamond, in spite of its extreme hardness and inertness, is not the stable form of carbon. Graphite is the stable form, hence the difficulty of transforming it into diamond. When diamond is heated in the absence of air, or in an inert atmosphere, it undergoes a slow surface blackening at temperatures above 600° C. The dark film is identical with graphite in chemical and physical properties. As the temperature is increased, the rate of inversion is accelerated.

The unique hardness of the diamond renders it extremely useful as a lathe tool for high-precision machining, such as turning objects like aluminium





FIGURE 1 — One of the principal recovery processes for diamonds is based on their adhesion to a greasy surface.



FIGURE 2—Diamond saw splits a drill-core rapidly and accurately for geological examination and chemical analysis.

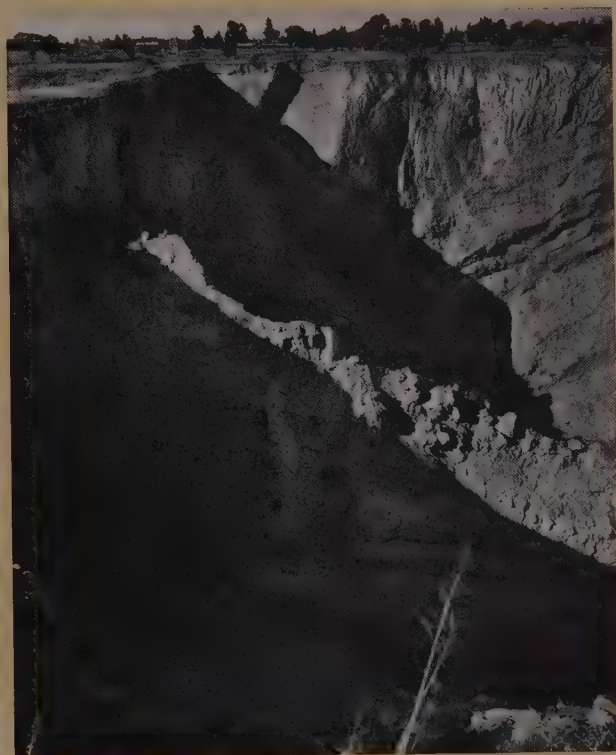


FIGURE 3—Before the development of underground mining, kimberlite pipes were worked from the surface. This gigantic hole at Premier Mine is one of man's largest excavations.

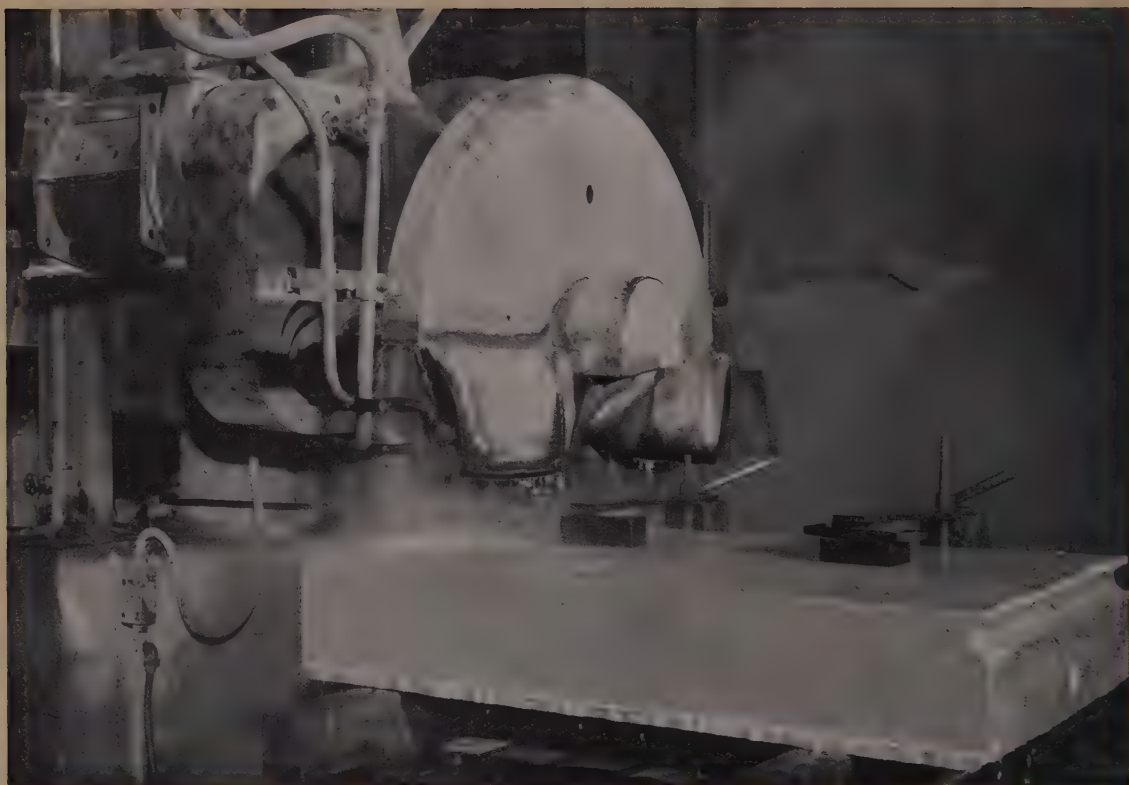


FIGURE 4 - Large diamond saw cutting through a block of building-stone.

pistons for motor car or aircraft engines [3]. The finish attained with the use of a diamond lathe tool is unsurpassed, and usually resembles a surface buffed or polished after machining with other tools. The watch industry utilizes diamond tools extensively for the fabrication to exacting specifications of a wide variety of metal parts. Many non-metallic objects like billiard balls, typewriter platens, and vulcanite pipestems are also turned with diamond tools.

Grinding is a very important part of modern machine-shop practice, and diamond grinding-wheels play a vital role in many operations of precision engineering [9]. Diamond particles set in a matrix of metal, ceramic, or plastic to form a grinding-wheel are essential in grinding tungsten carbide or similar hard materials to fine limits of accuracy. The edges and bevels of plate glass and safety glass are ground with diamond wheels.

Synthetic abrasive grinding-wheels, usually silicon carbide or aluminium oxide, can be restored to their original shape, or freed from metal particles which tend to glaze their surface, only by diamond abrasive wheel dressers [5]. A dia-

mond thread-forming nib is used to transfer accurately on to a grinding-wheel the profile required by various types of precision thread-grinding machines. These shaped diamond tools constitute a very important outlet for industrial diamonds.

Diamonds, in the form of small whole stones or of powder, are set in the periphery of a metal disk to give a saw which is widely used for cutting a variety of masonry and ceramic materials. In the stone-cutting industries, large diamond saws up to 6 ft in diameter are used for cutting marble, granite, sandstone, and other materials employed for building and monumental purposes. Smaller diamond saws are used for cutting earthenware pipes, tiles, and other ceramic articles, for making sections of drill cores and mineral specimens, and for cutting channel samples of rock underground. The diamond saw not only cuts much faster than other masonry saws, but produces a smoother surface which in many cases requires no further finishing operation.

Large quantities of industrial diamonds have been used for many years in the mining industry in exploratory drilling. A hollow steel rod having



a diamond coring-crown or bit fastened on its end is rotated to drill into rock. The coring-drill crown consists of a metal ring having diamonds set on its periphery, so that a core of rock is cut and can be withdrawn through the hollow drill for geological examination and chemical analysis.

There is another type of diamond drill used extensively in the mining industry, namely the non-coring or blast-hole. In this, the diamonds are set over most of the abrading face of the metal bit. When drilling, this crown does not leave a core, but removes the rock cuttings from the entire diameter of the hole. Into this drill hole is inserted the explosive for blasting. These non-coring or blast-hole drill-crowns are therefore employed not for exploratory work but for actual mining operations.

In addition to their use in the mining industry, diamond drills of a smaller size are employed in the engineering and construction fields for neatly and rapidly piercing glass, porcelain, tile, brick, concrete, stone, etc. Even the dental profession now makes extensive use of diamond-furnished drills.

It is over a hundred years since the diamond was first employed in wire-drawing, and with the rise of the electrical industries there has resulted a steady demand for industrial diamonds for this purpose. Wires are made by drawing a bar of metal through dies of successively decreasing apertures, and for fine wire, such as copper below 0.05 inch diameter, where dimensional tolerances must be kept very low, the great abrasion-resistance of the diamond is utilized to enable large quantities of wire to be produced without appreciable wear on the die. Diamond dies for wire-drawing are made by piercing a tiny hole in a high-quality industrial diamond with the aid of an electric discharge, or with a fine steel needle charged with diamond powder suspended in olive oil. Thicker wires are drawn through dies of tungsten carbide, which are themselves polished to size with the aid of diamond powder.

Increasing quantities of industrial diamonds

are utilized as polishing powders and pastes. Diamond powder is employed for sawing and polishing gem and industrial diamonds. It is also used for imparting a mirror finish to dies and similar objects of hardened steel and cemented carbides. A minor use, but one important scientifically, is the use of diamond powder in the preparation of metallographic specimens, especially for hard alloys or where several phases differing in hardness are present. Diamond powder is prepared by pulverizing diamonds in a variety of ways: by jaw crushing, roll crushing, ball milling, impact crushing, or pestle and mortar. The sub-sieve sizes, below 325 mesh, are separated into accurately graded fractions by sedimentation, elutriation, or centrifuging.

There are many other uses of industrial diamonds. The oldest, and the one which probably comes first to the mind of the layman, is as a glass cutter. Various engraving and marking tools for inscribing glass, porcelain, or metal are provided with a diamond point. The diamond is becoming increasingly used for gramophone needles, and as a cutting point for recording grooves in gramophone records and on the sensitive cylinders of dictating machines. The hardness of engineering materials is usually measured by the depth of penetration of a shaped diamond indenter under standard load conditions, as in the familiar Rockwell and Vickers testers. Diamonds have been used in special nozzles where resistance to abrasion is of great importance. A diamond may be employed as a counter of alpha, beta, and gamma radiation.

The diamond has found innumerable applications since man first discovered that its unique hardness and wear-resistance could be utilized for industrial as well as ornamental purposes. During the war and post-war periods the resources of the large mining companies were taxed to the utmost to keep pace with the demand for industrial diamonds. The expansion of existing recovery plants, and the technical improvements now in progress, are good grounds for hope that the current shortage may in due course be alleviated.

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# The nucleic acid of the chromosomes

J. A. V. BUTLER

The supreme importance of the cell nucleus as a coordinator of its vital processes and as the carrier of hereditary characteristics needs no present emphasis. Only comparatively recently, however, has there been sufficient exact knowledge to attempt to interpret the nucleus and its effects in chemical and physical terms. This article summarizes recent work on the physical chemistry of the type of nucleic acid found in the chromosomes.

In recent years a very large amount of work has been put into the study of the nucleic acids. The reason for it is the suspicion that these substances are concerned in the processes of cell reproduction. The extraordinary behaviour of the chromosomes in cell division has been closely studied by cytologists for many years, and the theory that the chromosomes carry the elementary hereditary units or genes of the organism is well established. It has been found by various techniques, such as ultra-violet absorption measurements, staining, and direct extraction experiments, that one variety of nucleic acid, now usually known as deoxyribonucleic<sup>1</sup> acid because of the presence in it of the sugar deoxyribose, is contained in chromosomes in considerable quantities, associated with proteins. Another nucleic acid, originally isolated from yeast, is widely distributed in the granular components of the cytoplasm. Probably every living tissue contains representatives of both types of nucleic acid.

I propose to discuss recent investigations on the deoxyribonucleic acids of which calf thymus, fish sperm, and wheat germ have most commonly been used as the sources. Much work has been done to characterize these materials. Their chemical properties have been found, and are represented fairly accurately by the formula shown in figure 1, which is a straight chain formed by the polymerization of nucleotides, each of which consists of a purine or pyrimidine base and the phosphate of the deoxyribose sugar, combined in the positions shown [1]. It is possible that a small amount of branching of the main chain occurs, but this has not been definitely established [2].

Four distinct bases are normally present in quantity, and a fifth, 5-methyl cytosine, has been detected in comparatively small amounts [3]. The approximate equivalence of the four commoner bases, as shown by the earlier analyses, led to the idea of a tetranucleotide unit containing one of

each kind of base, but more recent analyses have shown that this is only a rough approximation. The proportions of the bases vary according to the source of the material, and differ markedly from unit ratios. It has, however, been found by Chargaff and his co-workers [4] that the amount of adenine and thymine are nearly equal in all the specimens examined, and that the same is, less exactly, true of guanine and cytosine. The ratios of the former pair to the latter, however, differ markedly from one species or source to another. The table on p. 155 shows some of these results.

Two main types appear to occur: one the AT type, in which adenine and thymine are in excess, and another the GC type, in which the reverse is the case. It is significant that in all the types examined the amount of primary amino groups is equal to the amount of hydroxyls.

Coming now to the physical properties of deoxyribonucleic acid and its solutions, it would appear that progress is being made in distinguishing the actual form and state of the molecules. As a result of the X-ray analysis of orientated fibres of nucleic acid, Astbury [5] proposed a structure in which the flat rings of the bases were piled on each other at a distance of  $3.4\text{\AA}$  from one to the next. It is extremely difficult with atomic models to bring the bases as close together as this, in a structure in which each sugar is joined to two phosphate groups and each phosphate to two sugars in the positions shown in figure 1, but there is some doubt about how much distortion of the ether-oxygen bond angles is permissible. Figure 2a shows the model of an extended nucleotide chain in which the bases come at distances of about  $7\text{\AA}$  along the chain. This is the most extended form possible, but tighter packings can be made, such as that suggested by Furberg [6], on the basis of X-ray studies of the nucleotides, in which the phosphate groups are arranged in a zigzag fashion, at separations along the chain

<sup>1</sup> The spelling desoxyribonucleic is preferred in the U.S.A.



*Composition of deoxyribonucleic acids from different sources*

Constituent	Sperm (human)	Thymus (human)	Thymus (ox)	Liver (human)	Yeast	Avian tubercle bacillus
Adenine .. ..	0.29	0.28	0.28	0.27	0.30	0.12
Guanine .. ..	0.18	0.19	0.24	0.19	0.18	0.28
Cytosine .. ..	0.18	0.16	0.18	0.15	0.15	0.26
Thymine .. ..	0.31	0.28	0.24	0.27	0.29	0.11
Total recovery .. ..	0.96	0.91	0.94	0.88	0.92	0.77

direction of 3.4Å, and with the bases sticking out alternately on each side of the main chain. Figure 2*b* shows a model of an arrangement which is very similar to this. There are other possibilities, such as spiral forms, but the evidence available is insufficient to distinguish them. Infra-red studies [7] have demonstrated a certain amount of orientation of the bases at right angles to the fibre direction.

The most characteristic property of nucleic acid solutions is their high and anomalous viscosity. The cause of this and related properties has been the subject of many papers, and there has been a good deal of disagreement in the various views put forward. It appears, however, that a definite picture of the molecular state in such solutions is now emerging. The molecular weight, as determined by a variety of methods [8], has usually been found to be in the region of  $1-5 \times 10^6$ . If the molecule consists of unbranched nucleotide chains, this implies about 5000 such units in it. The exact shape, although all methods suggest an elongated form, has given rise to much difficulty.

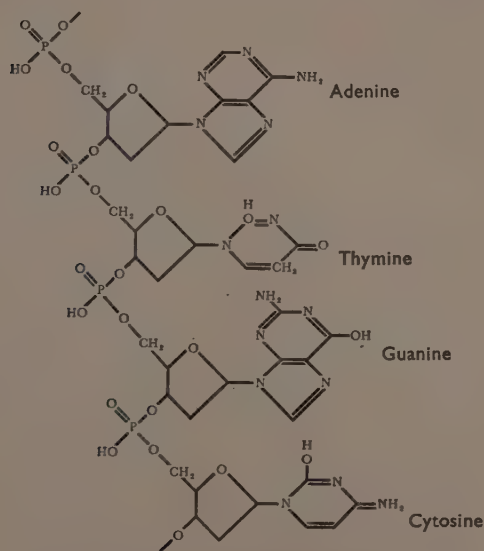


FIGURE 1 - Formula of deoxyribonucleic acid.

It has been found [9] that the viscosity is much reduced by the addition of quite small concentrations of salts, although it remains somewhat anomalous. Since the viscosity of polyelectrolyte solutions is similarly affected, and in the latter can be largely ascribed to the coiling up of the molecules when the electric repulsion of the charges is reduced by a strong double layer [10], it has been thought that the effect observed with nucleic acid is similar in origin [11]. This assumes that the nucleotide chain is flexible, but evidence is accumulating that its behaviour in solution is best accounted for on the basis of a fairly rigid rod-like structure. For example, Schwander and Signer [12], having shown that the streaming birefringence of solutions is independent of the salt concentration over a very wide range, suggest that this is compatible only with a rigid molecule. The dependence of the sedimentation constant on the concentration has also been interpreted as due to the behaviour of a felt-like mass of particles of the appropriate cross-section [13]. Lastly, measurements of the Kerr effect (birefringence in an electric field) by Benoit lead to a similar picture [14]. Information from light-scattering is at present inconclusive.

It therefore seems to be fairly clear that the effect of salts on the viscosity is unlikely to be due to the coiling of the molecule, and that it is most probably due to changes of the interaction of the particles with each other. That nucleic acid solutions show marked effects of molecular interaction except at extreme dilutions has been found in all observations—indeed, with most methods the difficulty is to reach concentrations so low that the effects are not apparent. These interactions are shown very strikingly in some recent experiments on the diffusion of nucleic acid into water and salt solutions [15]. In water, the diffusion gives rise to a very sharp diffusing front, which indicates that the molecules moving forward into the solvent are held back by those behind, as they would be if they were joined together in a network. The

amount of interaction is much reduced by even small salt concentrations. The picture of nucleic acid solutions which we form is thus of a network of rigid rods, probably held together at their points of attachment by electrostatic forces between positively and negatively charged groups, but possibly also by hydrogen bonds of a somewhat more permanent nature.

It will be of interest now to see if we can fit into this picture the actions of various reagents on the deoxyribonucleic acid. Acids and alkalis cause irreversible changes [16]. The viscosity is greatly reduced and does not completely recover when the solution is made neutral again. Solutions may also become thixotropic after such treatment [17]. Certain groups also become titratable which are not titratable if the nucleic acid has not been exposed to acid or alkaline conditions. The explanation suggested by Gulland, Jordan, and Taylor [16] is that hydrogen bonds formed between amino groups and hydroxyl groups of adjacent bases are broken by the acid or alkali, so that these groups then become titratable.

It has also been known for some time that substances like guanidine and urea decrease the viscosity of solutions of nucleic acid [18]. Conway and Butler [19] found that this effect is irreversible, i.e. the viscosity is not restored by removing the added substance. Phenol was found to behave similarly. Comparatively high concentrations, however, are required to produce the effect.

All these substances are known to cause breakage of hydrogen bonds, and by reason of this property they are effective as denaturing agents with proteins. It appears that they have a similar effect on deoxyribonucleic acid, which implies that the nucleic acid has some kind of structure maintained by inter- and intra-molecular hydrogen bonds. It is significant that Chargaff's analyses have shown a very close balance between the amount of primary amino groups and hydroxyl groups carried by the bases in all the nucleic acids examined. The existence of such hydrogen bonds will explain the stiffness of the nucleic acid molecule, and the formation of a network of stiff rods will explain the high and anomalous viscosity. It has been found that although the denaturing agents (urea and phenol) mentioned above decrease the viscosity (and in the presence of salts bring it down to very low levels), they do not very much alter the molecular weight as determined from diffusion constants and sedimentation velocity. The loss of viscosity is thus due primarily to the loss of interaction of the particles,

and perhaps also to the loss of stiffness caused by the folding up of the molecule into more compact forms when the hydrogen bonds which maintain the structure are broken.

Finally, we may mention the effect on nucleic acid of a different class of reagent, typified by the sulphur mustard  $S(CH_2CH_2Cl)_2$  and the nitrogen mustard  $CH_3N(CH_2CH_2CH_2Cl)_2$ .

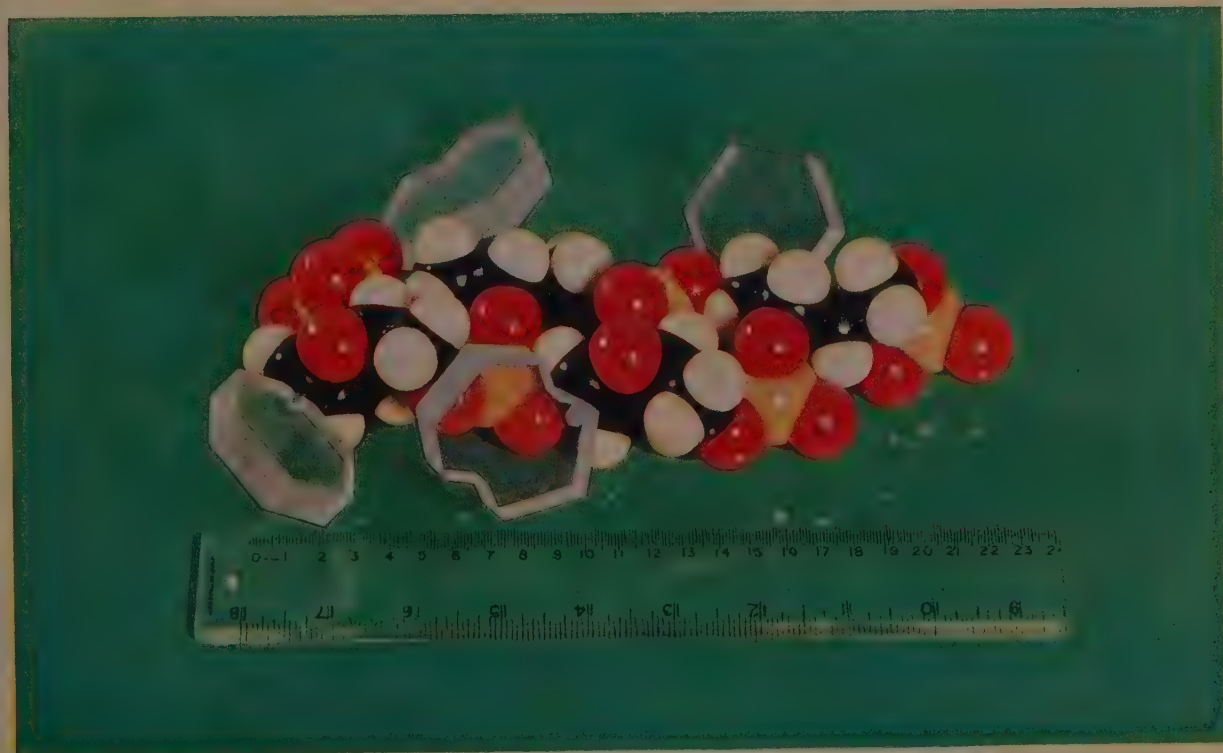
These and similar substances are known to produce striking biological effects [20]. They cause abnormalities in the mitotic process and inhibition of growth; they are mutagenic, and in some cases have been shown to cause cancer. The study of their action on nucleic acid was undertaken in the hope that it might throw some light on their biological activity. One of the most striking effects of these compounds, which they share with some other radiomimetic compounds (but not all), is the destruction of the high viscosity of deoxyribonucleic acid which they cause even at very low concentrations [21]. It has been shown that, among other chemical reactions [22], they combine with the primary amino groups of the bases (by alkylation); in doing so they necessarily break the hydrogen bonds in which the amino groups are implicated, and this will cause a denaturation similar to that produced by urea. However, other reactions occur with these reagents. It has been found that the initial product of the reaction is unstable and slowly breaks down into smaller units [23]. It is not at present known if this instability is due to the loading of the phosphate backbone of the nucleic acid with mustard residues, forming relatively unstable tri-esters of phosphoric acids. It is also uncertain which, if any, of these effects are significant biologically.

The function of deoxyribonucleic acid in the chromosome is still obscure. It has often been suggested that it acts as a kind of template, in which the highly specific peptide chains from which the proteins are formed are laid down, but it is difficult to see how nucleic acid could be capable of a sufficient number of variations [24]. Caldwell and Hinshelwood [25] suggested that if two of the entities present in the nucleic acid are involved in the formation of each amino acid residue, the permutations and combinations of four bases and one sugar taken two at a time provide the necessary number of possibilities. This, however, is an *ad hoc* hypothesis, and it is hardly fair to include the sugar. If the nucleic acid has a hydrogen-bonded structure like a protein, the number of possible configurations of even one nucleic acid molecule may be great, and it must





(a)



(b)

FIGURE 2 - Models of possible configurations of deoxyribonucleic acid. (a) The most extended arrangement of the nucleotide chain, in which the purine and pyrimidine rings all come on one side of the main axis and at distances apart of approximately  $7\text{\AA}$ . (b) A tighter packing in which the phosphate groups are arranged in a zigzag at horizontal intervals along the fibre of about  $3.4\text{\AA}$ . The purine and pyrimidine rings now come alternately on each side of the main axis at distances of about  $7\text{\AA}$  from each other. Yellow = P; red = O; black = C; white = H. Perspex cut-outs = purine and pyrimidine rings. Scale:  $1\text{ cm.} = 1\text{\AA}$ .

be remembered that, in extracting nucleic acid from the nucleoprotein, many of the details of the configuration may be lost. However, the possibility remains that the nucleic acid may not be the basic self-reproductive system. It may act only as a support for the proteins. It has been suggested by F. Haurowitz [26] that the function of the nucleic acid is to hold the peptide chains in an extended form while they are being copied, i.e. while a second chain is laid down by a process akin to crystallization. It might perhaps be of interest that, in the zigzag arrangement of the phosphate groups (figure 2*b*), there are two parallel rows of phosphate groups; if a peptide chain were held to one row, it may be supposed that a copy could be laid down on the second. On this idea, the function of the phosphate groups would be to anchor the peptide, while the amino and hydroxyl groups of the bases would keep the nucleic acid in a particular configuration and so control the configuration of the protein.

Against this we have to put the discovery, by Avery, MacLeod, and McCarty [27], that apparently pure samples of deoxyribonucleic acid can be obtained with the biological property of

being able to induce the transformation of *Pneumococcus* type II into the encapsulated variety type III. This ability is immediately destroyed by treatment with deoxyribonuclease, so that it appears to depend on the presence of the polymerized nucleic acid. Similar deoxyribonucleic acid fractions from the haemophilous influenza B have since been found to perform bacterial transformations. The evidence that a fraction of deoxyribonucleic acid itself is capable of bringing about an inherited change, and therefore of acting as a gene, is thus quite strong.

No static experiments can give definite information on protein synthesis, and it may be mentioned—although the work is outside the scope of this article—that much research is being carried out with radioactive compounds to distinguish the stages of both nucleic acid synthesis and protein synthesis.

#### ACKNOWLEDGMENTS

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# Synthetic rubber

W. J. S. NAUNTON

The term synthetic rubber is a misnomer—and in some respects an unfortunate misnomer—since the hydrocarbon of natural rubber, *cis*-polyisoprene, has so far eluded all attempts to synthesize it. However, the name synthetic rubber is commonly applied to any synthetic product which exhibits the chief characteristics of natural rubber, such as high extensibility with quick recovery. Dr Naunton's article deals with some of these products, and is complementary to Dr Treloar's article on natural rubber, which appeared in our April issue.

The successful development of a synthetic rubber industry was occasioned by the emergency of war. In the conflict of 1914–18, Germany was forced to manufacture synthetic rubber in an attempt to defeat the British blockade, and during the second world war the Americans made vast quantities of it to offset the effects of the Japanese occupation of Malaya and the Dutch East Indies. In the period between the two wars, synthetic rubbers (such as neoprene) which can be used for special purposes for which natural rubber is not suitable, were successfully produced, but in quantities amounting to only a few per cent. of the natural rubber output.

The retarded growth of the industry is explained by the facts that the synthetic products were much more expensive than natural rubber, and were not as good in processibility and in service for general purposes. The quality of the synthetic products, however, has been steadily improving and will certainly continue to improve, as a result of investigations conducted on strictly scientific lines in industrial rather than university research laboratories.

The quality of synthetic rubber is now such that it can be used in the production of tyre casings and inner tubes, and since tyres represent the major use of rubber it follows that the synthetic products have for the first time a chance of competing successfully with natural rubber. A factor in their favour has been the high price of the natural product, and though this cannot be expected to continue at the same level when emergency stock-piling is completed, changing economic and political conditions in the Far East make it doubtful whether the price will ever return to a figure comparable with that of twenty years ago.

It should be emphasized that the expression 'general purposes rubber' has little significance as applied to synthetic products; it serves merely as a good description of natural rubber. As a matter of fact, industry does not wish for a general purposes

synthetic rubber; it would prefer special products for specific applications. If we remember that the innumerable types of article made from rubber have been manufactured by processes based on the characteristics of the natural substance, it is easy to understand that natural rubber provides the common denominator of all the special properties required in the raw material for these products. Basically, for example, natural rubber is not the ideal raw material for the manufacture of tyres or ebonite—it is merely a rubber which will serve these and many other purposes reasonably well. Special-purpose rubber made synthetically will give tyres with greater mileages, tubes which require less frequent inflation, and ebonites with higher softening-points. In short, the trend in rubber manufacture is from the general towards the special.

It has already been mentioned that natural rubber is superior to most synthetic rubbers in processibility, i.e. it can more easily be handled, shaped, and converted into the finished article. This fact, coupled with empirical methods and conservatism in the industry, told against the adoption of synthetic products, but the outlook has at length changed and much progress is being made. Practically all the large rubber companies now have their own research departments, which rank among the finest in modern industry. There is, of course, much to be said for attempting to evolve a synthetic rubber which could be processed in existing machinery, for the capital outlay has been very large; on the other hand, there is little doubt that the industry would be prepared to modify its machines and techniques if a synthetic product could be found which gave outstanding results but could not be processed in the present equipment. The kind of problem involved may be illustrated by the fact that natural rubber, in its uncured state, can be kept almost indefinitely before conversion into the final vulcanized product.

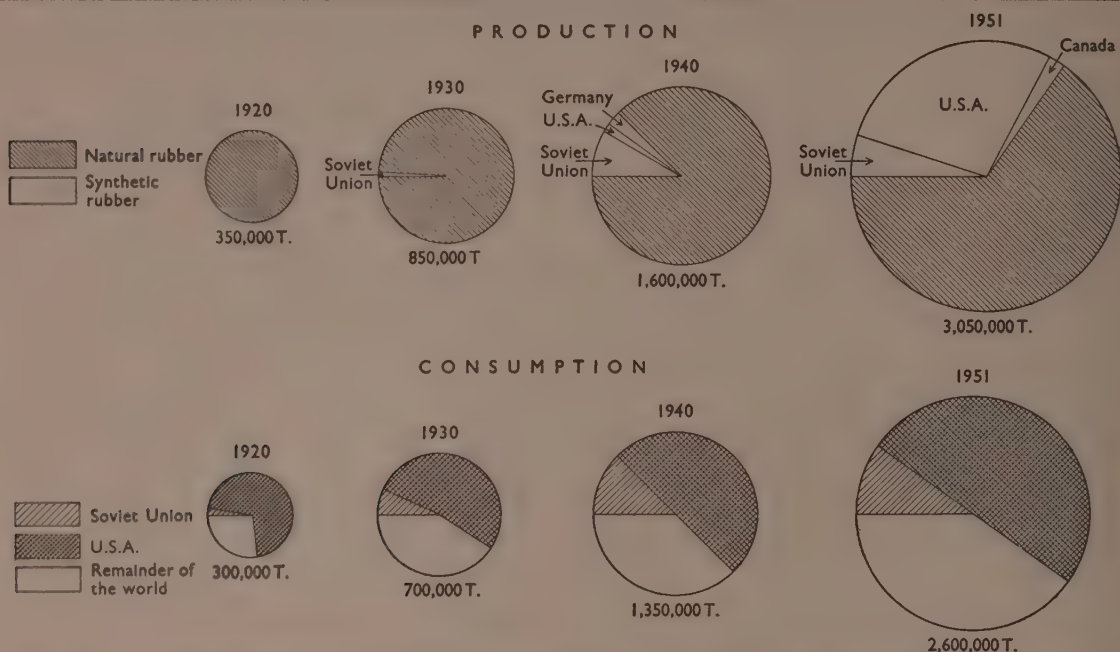


FIGURE 1 - Total world production and consumption of rubber. T=long ton. (Rubber-Stichting, Delft, Holland.)

Synthetic rubbers do not always possess this stability, and in some cases the last stage in their production must be carried out in the rubber factory immediately before conversion.

The essential characteristics of a rubber are that, at temperatures over a practical working range, it shall consist of long flexible molecular chains (see ENDEAVOUR, II, 93, 1952) capable of being cross-linked to form a three-dimensional structure by some preferably simple treatment, such as heating. The mobility of the chains is most important, since upon it depends the resiliency of the rubber. There must thus be no tendency to crystallization (or, probably more accurately, alignment) at working temperatures, though there is no drawback in the crystallization that may occur on stretching. Such alignment cannot be regarded as a specific feature of a rubber, since some of the accepted synthetic rubbers do not show it. Generally, the synthetic rubbers which do not align on stretching must be reinforced with carbon black; hence they suffer from the disadvantage of being unusable as gum (i.e. unreinforced) stocks. Neoprene, however, shows a fibre structure by X-ray examination when it is stretched and can therefore be used in gum stocks in the same way as natural rubber, but the butadiene co-polymers do not give fibre pictures and cannot be so employed. Long-chain molecules with the greatly reduced mobility

caused by hydrogen-bonding crystallize when stretched at room temperature, and when the tension is released they do not return to their original state of disorder. As a result of this treatment, they show a great increase in longitudinal strength and a great decrease in extensibility: in other words, they then have reduced resilience and exhibit an ideal fibre structure. Nylon and Terylene, for example, are long molecules which have been fixed in alignment by the process of cold drawing. If unevenly distributed additional groups are introduced into the uniform nylon molecule, it loses its tendency to easy alignment and is converted into an elastic form which does not possess the stability of ordinary nylon.

Though the basic requirement for resilience is the presence of long unbranched straight chains of great flexibility, another factor has to be taken into consideration. This is the freedom of the long chains from admixture with short chains, or 'chain debris,' which would hinder the movement of the long chains in returning to their position of disorder. These detrimental short chains can arise either from faulty polymerization or, later, by chain scission during ageing. It is therefore essential to select polymerization conditions which give a narrow molecular distribution, similar to that in natural rubber; but there is in general no need to consider chain scission, since as a rule the ageing



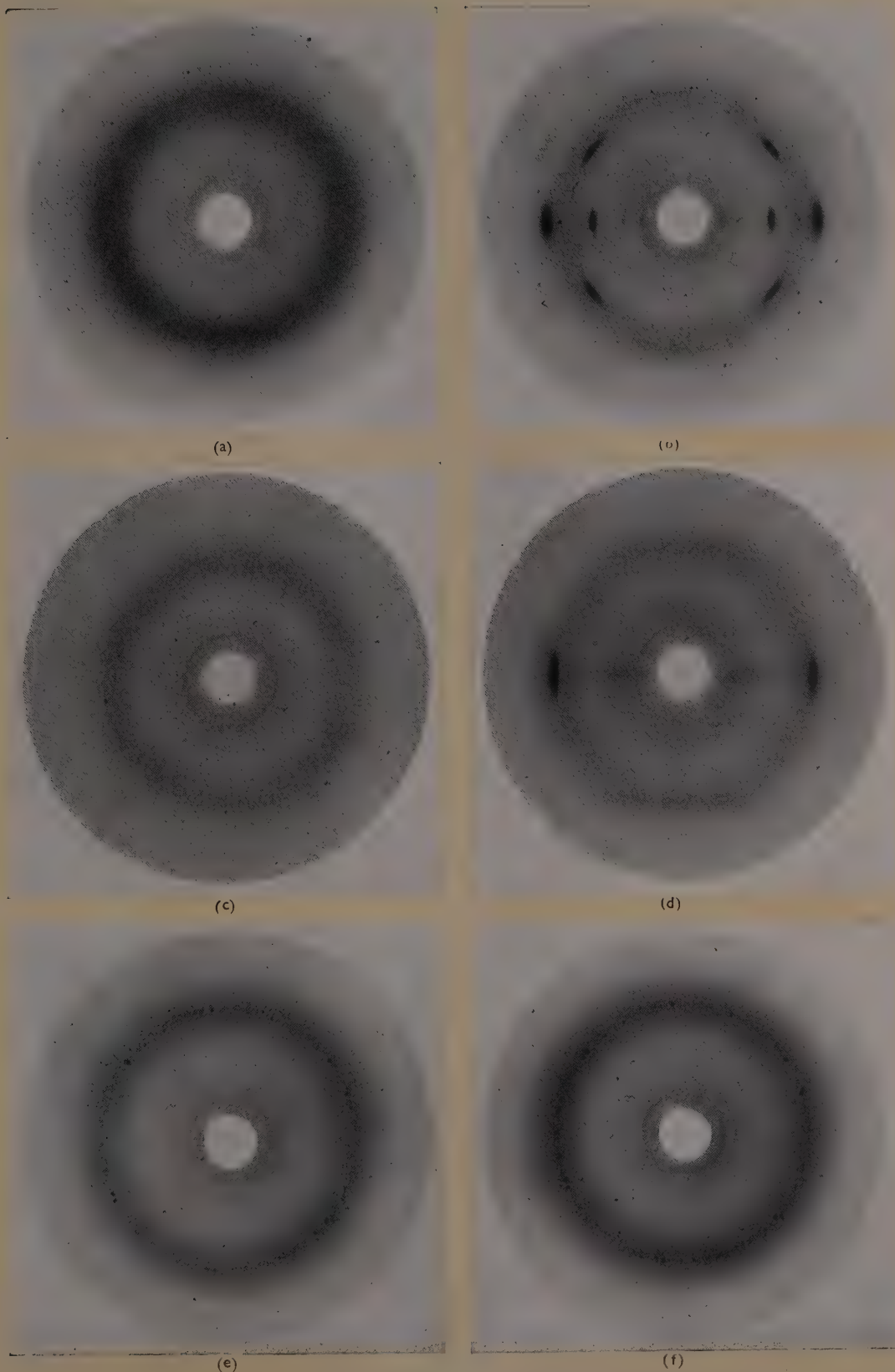


FIGURE 2 - (a) Natural rubber, gum stock. Unstretched. (b) Natural rubber, gum stock. Stretched 300 per cent. (c) Neoprene, gum stock. Unstretched. (d) Neoprene, gum stock. Stretched 300 per cent. (e) GR-S, gum stock. Unstretched. (f) GR-S, gum stock. Stretched 100 per cent. (maximum possible). (X-ray photographs.)

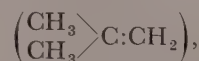
of synthetic rubbers by scission due to oxidation, as distinct from that caused by gel formation due to cross-linking, is far slower than that of natural rubber. The primary requirement, namely the initial production of long straight chains, is not so easy to accomplish. We do not know how rubber (*cis*-polyisoprene) and gutta (*trans*-polyisoprene) are produced in their respective trees, but we do know that the tree exerts a perfect control over the formation of long straight chains. It is interesting to note that it has recently been found, by Leeper, that the chicle tree or sapodilla (*Achras sapota*) can simultaneously produce both *cis* and *trans* polymers in admixture, but no case is known of a tree producing a mixed polymer.

The most familiar general purposes rubber of the second war period, known in Germany as Buna-SIII and in America as GR-S, is a co-polymer<sup>1</sup> of butadiene ( $\text{CH}_2\text{:CH}\cdot\text{CH}\cdot\text{CH}_2$ ) and styrene ( $\text{C}_6\text{H}_5\text{:CH}\cdot\text{CH}_2$ ), and was ascertained to be a complex structure with considerable side-branching. German workers discovered that the branching could be reduced by conducting the emulsion polymerization at temperatures lower than those normally employed, but this method was not put into practice since the reaction then took several days. Some ten years ago, it was found independently in England, America, and Germany, that reduction-oxidation catalysis could be applied to emulsion polymerizations. This method was so rapid that it could not be applied to the contemporary technique of emulsion polymerization in bulk, and two new variations of procedure were developed in Germany: (i) a continuous, instead of a batch, process, in a tubular system which enabled effective cooling to be given; and (ii) a batch process at lower temperatures. The second variation gave a good product with no increase in the time of reaction; it was applied with great success in the U.S.A. to the GR-S process, and resulted in what is now known as cold rubber. Investigation by physical methods (notably X-ray examination), and by chemical analysis of oxidation products, has shown that cold rubber has a less complex, and hence more desirable, structure than GR-S. It is particularly suitable for tyres, and, if used in combination with the appropriate forms of carbon black, is found to give excellent resistance to abrasion.

A recent development in the field of GR-S is the development of the oil-extended grades. By mixing an emulsion of mineral oil with the poly-

mer at the latex stage the final coagulated product is more workable in the rubber factory and so a tougher and better grade of polymer can be employed. It also lowers the cost of the product without any serious loss of quality.

A synthetic product extremely useful for inner tubes is known as butyl rubber. It was shown in Germany that *isobutylene*



a well-known by-product of oil-refining and an intermediate in the manufacture of high-octane fuel, could be mass-polymerized with a boron fluoride catalyst at very low temperatures, giving a substance somewhat resembling a synthetic rubber. It could not, however, be regarded as a true member of the class, since, owing to the absence of centres of unsaturation, it could not be vulcanized and was therefore thermoplastic. Later, it was discovered in America that co-polymerization of the *iso*-butylene with butadiene, or, better, with isoprene



gave a product which could be vulcanized slowly. This product is described as butyl rubber, and though it proved more troublesome to manufacture than was originally anticipated it has now established itself as undoubtedly the best rubber for use in inner tubes. It is interesting to note that while this solvent technique for butyl was regarded as unique it now looks as if solvent polymerisation with the new organo-sodium catalysts may eventually replace the emulsion technique. Experience has shown that such tubes maintain their air pressure some ten times as long as those made of natural rubber.

Another very important synthetic rubber is neoprene, which was developed in America in the early 1920's. It is made by the emulsion polymerization of chloroprene



It is far more resistant to oil than natural rubber is, and owing to its high chlorine content is flame-resistant; moreover, it is not attacked by white ants, a property which makes it valuable for tropical use. Neoprene is widely used in industry, and there is little doubt that a good deal more would find application if sufficient supplies were available. Other oil-resistant rubbers, also made by emulsion polymerization technique, are the

<sup>1</sup> Co-polymerization occurs when two or more different molecular species polymerize with one another.



butadiene-acrylonitrile co-polymers such as Buna-N and Hycar. They are slightly more effective than neoprene for certain purposes, and possess the advantage of being miscible with polyvinyl chloride.

The last important variety of synthetic rubbers is the group of butadiene-styrene co-polymers with a high styrene content. It is perhaps hardly appropriate to describe them as rubbers, for they are not resilient but resemble resins; they are in fact internally plasticized polystyrenes. Their chief use is in combination with GR-S for making rubber soles and heels having many of the desirable properties of leather. Their latices, after pigmentation, are employed as adherent, quick-drying, and washable paints for interior decoration.

It is interesting to speculate on the future of synthetic rubbers. Vast sums of money are being spent in America on research in this field, and curiously enough the problem is being attacked from what might appear to be two diametrically opposed points of view, namely on the one hand the use of three or even four monomers, and on the other the employment of butadiene alone. In view of the uncertain international situation, increasing importance is being attached to the properties of new synthetic rubbers at Arctic

temperatures, and to their oil-resisting capacity as measured against the special fuels used in jet-propelled aeroplanes and guided missiles. The problem has been met to some extent by the modern silicone rubbers, which are, however, too expensive for general use.

Interest also centres on the condensation rubbers (*Vulkollans*) developed in Germany during the second world war. These products possess very useful physical properties, such as high strength, remarkable resilience, and great resistance to tear and abrasion. They have serious defects also—due probably to a low degree of cross-linking and a tendency to hydrolyse. It is not at all clear how these defects could be overcome, since any attempt to protect the ester groups by close packing would result in loss of elasticity. The problem is under investigation and may be solved by placing large groups round the ester linkages, but this would probably be very costly.

The possibilities of a synthetic rubber industry in Britain depend upon the availability of the raw materials, the chief of which are ethylene, acetylene, butylene, and benzene. Some of these hydrocarbons are produced in petroleum-refining, and most of them can be obtained by cracking petroleum or the oils derived from coal.

## Book reviews

### THERMODYNAMICS

#### OF IRREVERSIBLE PROCESSES

*Thermodynamics of Irreversible Processes*, by S. R. de Groot. Pp. 242. North-Holland Publishing Company, Amsterdam. 1951. Fl. 17.50 net.

The laws of thermodynamics are concerned with the properties of matter in equilibrium, and with the changes that take place in a physical system when it passes from one equilibrium state to another equilibrium state. But there is a whole class of physical phenomena which are concerned with steady-state, as distinct from equilibrium, processes. An essential feature of these phenomena is that they involve irreversible processes, such as heat conduction, thermal diffusion, and so forth.

The earliest attempt to examine them was Kelvin's treatment of thermo-

electric effects. He assumed that the irreversible and the reversible effects could be separated, and that the laws of thermodynamics could be applied to the latter. This hypothesis was to be tested by comparing the results so obtained with experiment, and it was vindicated. The same hypothesis was applied to examine other phenomena in which irreversible effects occurred: it provided a rule of thumb, but no explanation of why it was valid.

The further development is due to Onsager, who applied the general principle of microscopic reversibility in mechanics to establish certain macroscopic relations between the parameters used to describe the irreversible processes. These reciprocal relations (as they are called) are used in conjunction with the equations of entropy production and entropy flow for the

irreversible process in question, to set up equations which describe the phenomenon. This provides a general process for describing such phenomena, and explains why Kelvin's method leads to correct results.

This book is the first systematic account to be published in English of these developments in thermodynamics, and has the advantage of being written by one who has made an important contribution to the subject. In the first two chapters the author gives an account of the foundations of the theory; in the next seven chapters he examines the application of the general theory to a wide variety of physical and chemical topics; in the closing two chapters there is a further critical examination of the foundations of the theory. A very full bibliography of papers on the subject is included.

A. R. MILLER

PLANT PHYSIOLOGY

*Principles of Plant Physiology*, by J. Bonner and A. W. Galston. Pp. 499, with numerous figures in the text. Freeman and Company, San Francisco; Bailey Bros and Swinfen, London. 1952. 47s. net.

The authors of this one-semester course in plant physiology lay it down that an elementary textbook must be as far as possible a synthesis of existing knowledge into a single working hypothesis. This, they say, must and can be achieved without becoming dogmatic. It is extraordinarily difficult to see how so diverse, and so rapidly and erratically developing, a subject as plant physiology can be brought at any level within the bounds of a conceptual unity; furthermore, the nature of the subject being what it is, much harm and little good would seem to be the most likely result of so unpromising an attempt.

In the actual working out, the authors have not so strait-jacketed themselves as they threaten; the choice of topics is reasonable and up-to-date; the language is simple and unambiguous. The net result is, however, to lull to sleep any tendency on the part of the student towards original inquiry, by answering all questions before he can ask or even formulate them. Concerning, for example, the difficult question of the oxidation of pyruvic acid in plant tissues, the authors admit no doubts, but describe the mechanism in positive terms down to the last hydrogen transfer. The looseness of thinking which could accept their account of 'three basic experiments' as a justification, and which would be encouraged in any young students who read it, is not pleasant to contemplate.

The arresting feature of the book is, however, its numerous illustrations, drawn with a confidence that is overwhelming. As draughtsmanship, they have a firm clarity which is all the more unfortunate in view of their scientific shortcomings. As illustrations, they vary between the unnecessary, the misleading, the erroneous, and the silly. Why, for instance, should metabolic energy be represented as an electric discharge, or an amylase chain be shown in diminishing perspective to the far distance? Why should root-hairs be shown contracting regularly in length from a maximum near the root apex, and how does it help to draw the prosthetic group of an enzyme as a cube attached to an orange? May not such things even be seriously misleading to

the innocent novice? The drawing illustrating the transpiration stream would suggest to a beginner that the spiral thickenings of vessels impart a spiral twist to the ascending water—a novel theory which the authors had not, perhaps, seriously contemplated; but the drawing of a stoma on the same page is so ludicrously erroneous that one cannot feel sure. It is perhaps not usual to form one's estimate of a textbook mainly from its illustrations, but in this one they so savagely attack the eye that there is an actual physical difficulty in reading the text around them. In addition, the damage which they are capable of doing to the student could scarcely be put right by the most inspired textual exposition.

W. O. JAMES

CARBON DIOXIDE FIXATION

*Carbon Dioxide Fixation and Photosynthesis. Symposium of the Society for Experimental Biology, V.* Pp. 342, with several plates and numerous line diagrams. Cambridge University Press, London. 1951. 42s. net.

The area covered by this symposium represents a very wide and interesting section of recent metabolic studies. Both subject matter and treatment vary extensively among its twenty-one papers, all of which are statements at first hand by prominent architects of the subject. The first five papers are concerned with the biological fixation of carbon dioxide by mechanisms independent of light. This is shown to be of wide distribution among animals, bacteria, and plants and to occur in more than trifling amounts. It is responsible for the extensive accumulation of plant acids in the *Crassulaceae*, but its general biological significance, if any, is still to seek. The remaining contributions are concerned with photosynthesis and varying aspects of its physico-chemical background, as well as with more directly biological systems. The results of recent work with carbon dioxide labelled with  $C^{14}$ , now tending to coalesce into agreed and credible systems, are reported from two independent sources. The attempt to determine maximal quantum efficiencies is still much less harmonious, and opposing views are given with a wealth of experimental detail, essential to the specialist in this strenuously contested subject, but rather forbidding to others.

In sum, this is a worthy record of an important conference happily con-

ceived by a society that takes all experimental biology for its province.

W. O. JAMES

USES OF SEAWEED

*Seaweed Utilization*, by Lily Newton. Pp. 188, with numerous half-tone and line illustrations. Sampson Low, Marston, and Company Limited, London. 1951. 21s. net.

This book gives in a non-technical manner some account of the seaweeds and the uses that man has made of them. The examples cover a wide range from their direct use as food by the Chinese as long ago as A.D. 300 to the latest development of such alginate products as rayon yarn in modern textile manufactures.

The author, Professor Lily Newton, who is well known as an authority on British marine algae, took a leading part in the wartime survey of the British algal resources. Chapters on special subjects have been contributed by leading workers in those fields: J. B. Speakman on seaweed rayon, S. M. Marshall and A. P. Orr on the artificial culture of marine algae, K. A. Pyefinch on seaweeds as fouling organisms and on anti-fouling paints, and an appendix by M. Knight on the larger brown seaweeds of the British coast.

It is noticeable that, while seaweeds may play a role in normal peasant subsistence agriculture—as in the Arran Isles—there are inherent difficulties in their use as raw materials in industry by western peoples. Not only is the collection of certain species limited to a couple of hours or so at low tide each day, but bad weather or short hours of daylight may prevent any collection at all. The raw material is wet, heavy, and bulky and has to be dried before it can be marketed. In times of national crisis these difficulties might be overcome, but in normal times the nature of the work and the low rate of remuneration cause the harvest to fall away. During the Napoleonic wars there was a rise in the kelp industry along much of the western seaboard of the British Isles, but it languished in the ensuing peace. In the 1914-18 war, the need for potash caused a revival in the collection of brown seaweeds, which declined when supplies from mineral deposits again became possible. During the late war, the need for a local supply of agar-agar became urgent, since the Japanese had established a virtual monopoly in this important substance.



In Britain, America, and Australia sufficient algae of the appropriate species were located, and agar of excellent quality was made. It is to be hoped that the difficulties of harvesting will not cause this industry to languish.

The complex colloidal polysaccharides which are the product of synthesis in the algae differ so much in their properties from those of the cellulose- and lignin-producing land plants that their use as sources of rayon has only recently become possible. Provided that the regular supply of raw material essential to a modern manufacturing process can be maintained, it may be that the utilization of seaweed will find a prominent place in modern industry.

The book is lavishly illustrated with 74 half-tone plates, many of them pictures of considerable artistic as well as technical merit. The rather high price for a book of under 200 pages probably results from the number of illustrations. The absence of an index is regrettable, as are certain slips in English, e.g. immigration is twice used where clearly emigration was intended.

T. G. B. OSBORN

#### ELECTRICAL PHENOMENA AT INTERFACES

*Electrical Phenomena at Interfaces. Edited by J. A. V. Butler. (Contributors: J. O'M. Bockris, T. R. Bolam, P. A. Charlwood, J. M. Creeth, W. F. Floyd, M. B. McEwen.) Pp. 309. Methuen and Company Limited, London. 1951. 32s. 6d. net.*

This book is a revised edition, with much enlarged scope, of the editor's 'Electrocapillarity.' It begins with two chapters on the origin of phase boundary potentials, the electrical double layer, and electrocapillarity, including a brief account of the Debye-Hückel theory, and proceeds logically to electrophoresis, including a detailed account of the study and purification of proteins by electrophoresis, and a brief note on ionic crystals; then follows a summary of modern views on the stability of lyophobic suspensions. The next section contains three chapters on irreversible electrode phenomena; those on overpotential, and on films of oxygen and hydrogen at electrode surfaces seem full and abreast of modern work; the chapter on concentration polarization and the deposition of metals is perhaps rather less thorough. So much ground is covered that some of the text

reads like rather disconnected notes, but with sufficient trouble the reader can follow the argument, and very many references are given. The book ends with two chapters on membrane potentials and electrical phenomena at the surfaces of living cells, with particular reference to excitation processes in muscle and nerve.

The book is most valuable, the topics being well chosen and the treatment generally fuller and more up to date than can be found anywhere else. It should be very useful to physical chemists and biologists, both as a coherent textbook and as a work of reference. The plan and editing are much better than in most works by several authors, and the price is moderate—for the present day.

N. K. ADAM

#### THE BARKER INDEX

*The Barker Index of Crystals, edited by M. W. Porter and R. C. Spiller. Volume I, in two parts, 500 + 1000 pages. W. Heffer and Sons Limited, Cambridge. 1952. 120s. net.; first part separately 30s. net.*

The late T. V. Barker's system of crystallo-chemical analysis is based entirely on study of the face development. A few rules, foremost of which is that of assigning so-called simple indices to the maximum number of developed planes, enable independent workers to choose axes and face symbols for any crystal in the same way as the followers of Barker who have compiled the catalogue, and hence to select from the numerous interfacial angles those which are used for its classification in the index.

Volume I deals with 3000 crystals, mostly orthorhombic, the rest tetragonal, hexagonal, or trigonal. Later volumes will deal with a further 5000, mainly monoclinic, crystals.

Part I, which is separately bound, has an elementary introduction to crystallography by L. W. Codd, intended to show any doubtful starter that the technical knowledge necessary for application of the method is not difficult to acquire. For specialists there is a more advanced treatment by M. H. Hey. In addition to classification angles, Part I includes tables of densities, melting-points, and optical properties.

Part II contains descriptions of each crystalline substance. It includes, in condensed form, all the information in Groth's *Chemische Kristallographie*, with

corrections, and has cross-references to the ASTM X-ray data. Representing many years of work by the editors and others, it should prove a valuable work of reference for all crystallographers, apart from uses it may find in the analytical field.

H. M. POWELL

#### PRENATAL TRANSFER OF ANTIBODIES

*Antibodies and Embryos, by W. F. Rogers Brambell, W. A. Hemmings, and M. Henderson. Pp. 103, with several line diagrams. University of London. The Athlone Press, London. 1952. 12s. 6d. net.*

In this book Brambell and his colleagues give a concise account of their investigations into the transfer of antibodies from mother to foetus. The substance of the book consists of lectures given by Brambell in the University of London in October 1950. His work gives an entirely new understanding of the passage of maternal antibodies to the newborn rabbit, and, as he says, 'the theory relating the transfer of immunity to placental structure falls to the ground so far as the rabbit is concerned.'

The opening chapters, which include original work, deal with the anatomy and physiology of reproduction in the rabbit and provide a background to what follows. Subsequently, Brambell unfolds the story of his own experiments and the delicate operative techniques which he has developed. Finally he gives us his views on the wider implications of this work. He stresses here that the results of experiments in the rabbit should not be taken to apply to other species, and indeed the theme of the whole book is that similarity in structure does not necessarily mean similarity in function. The volume concludes with a useful bibliography. Altogether this is a most stimulating and valuable book, essential to all interested in the field of placental permeability.

R. M. CALMAN

#### A BOTANICAL CLASSIC

*The Origin, Variation, Immunity and Breeding of Cultivated Plants, by N. I. Vavilov. Translated by K. Starr Chester. Pp. viii + 364. The Chronica Botanica Company Inc., Waltham, Mass.; Wm. Dawson and Sons Limited, London. 1951. \$7.50.*

This book is a translation of Vavilov's

part in a symposium which he edited on 'The Scientific Bases of Plant Breeding.' This work of 2500 pages appeared in Moscow in 1935. In 1940, shortly before he disappeared, Vavilov arranged with the present reviewer to have it translated in Russia in the hope of publishing it in England. The work has now been done in America.

The whole of Vavilov's contribution is brought into focus in these 364 pages: his understanding of botanical systematics, its genetic basis, its bearing on the origin and future of cultivated plants, on their physiology and their geography, and particularly the complex relations of these plants with their pests and diseases and with the changing methods of human cultivation and utilization.

That this is the most important work on cultivated plants since Darwin and de Candolle is at once obvious. Only more slowly will it appear that the breadth of Vavilov's treatment is something new in science as a whole. Let those who inveigh against the sterilizing specialization of modern scientists take note. Here is a man who knows his seemingly narrow subject of wheat as no other man has ever known it. But he knows it from China to Peru, from the Swiss lake-dwellings to the American bakery, from the chromosomes under the microscope to the diseases in the field. And through his knowing it, his work has become an inspiration, not only to the wheat specialist, or the plant breeder, or the botanist, or the agriculturist, but to anyone who is interested in the history and achievements of man.

The present publication is a monument to the achievement of Vavilov, and indeed of Russian science, in the transitory period between revolution and the new epoch of what we may call regulation. C. D. DARLINGTON

THE BUILDING-STONES  
OF MODERN PHYSICS

*Elementary Particles, by E. Fermi. Pp. 110. Oxford University Press, London. 1951. 12s. 6d. net.*

In the last century it was the rule for the leaders in theoretical physics to be the leaders in experiment also. Stokes, Kelvin, Rayleigh, and J. J. Thomson, to name only British physicists, are instances that come quickly to mind. Now it is the exception, and Enrico

Fermi is the most notable example in the world. Being without question in the first rank in both departments of physics, he is the ideal man to explain to the experimenter what the theoretical physicist is trying to do. It is not an easy task. Modern theoretical physics is trebly difficult: it uses difficult mathematical techniques; the ideas with which it deals are abstract and far removed from ordinary experience; and, worst of all, these ideas are not precisely formulated, so that they have to be applied rather by intuition than by precise logic. Nowhere is this more apparent than in the study of the so-called elementary particles, which aims at explaining, and if possible predicting, the properties of the group of entities with names ending in 'on' which are, in some not very easily definable sense, the building-stones of modern physics.

There was a time, not so very long ago, when the world seemed built of electrons and protons and of these only, unless quanta or photons were considered permanent enough to count. We are far now from such simplicity. First the positron, then the neutron, and now the multiplicity of mesons, of which new varieties are being discovered almost monthly, make a bewildering picture.

The positron was predicted by Dirac, and so fits into the theoretical picture; the neutron had been suspected by Rutherford, though on very general grounds. The mesons, though suggested on theoretical grounds by Yukawa, have turned out to be very different from what their conceiver supposed. There is a considerable family resemblance in the theories that attempt to account for these particles, but it is fair to say that they present features which, though demanded by experiment, hardly seem to develop naturally from the root ideas. One cannot help thinking that there will be some very fundamental changes in the next few years.

Fermi has presented these ideas for the benefit of the experimentalist with the minimum of mathematical technique and great lucidity, but even his skill cannot make this book very easy reading. It will, however, be indispensable to the experimental physicist who wishes to have some idea of where the subject is tending, and to understand some of the reasons that lie behind the often enigmatic statements of his theoretical colleagues. G. P. THOMSON

BEHAVIOUR OF LIVING ORGANISMS

*The Study of Instinct, by N. Tinbergen. The Clarendon Press, Oxford. 1951. Pp. vii + 228. 25s. net.*

It is completely impossible in a short notice, such as this must be, to do justice to the richness either of the material or of the argument of this book. Tinbergen has attempted to present a synthesis of the direct observational and experimental studies in animal ethology carried out, mostly in central Europe, and mainly under the influence of K. Lorenz, during the last twelve years or so. While this book is meant chiefly for the student of zoology, it is of equal interest to the physiologist, to the psychologist, and in fact to everybody who is prepared to treat seriously the systematic study of the behaviour of living organisms from the point of view, as the author frequently insists, of its causation.

In this volume Tinbergen is principally concerned with behaviour (i.e. 'the total of movements made by the intact animal') which has not been changed by learning. The general view is that all such behaviour is due to a combination of external (stimulus) factors which may have both a release and a directive function, and of internal (alternatively called motivational or neurological) activities. Abundant examples are given of each and of both together, in the course of which many attempts are made to arrive at accepted principles of their action and interaction. Later discussions deal with the development of behaviour in the individual, with the property of adaptiveness in behaviour, and with problems of the general evolution of behaviour.

The volume is admirably produced, with many pictorial illustrations and with a full bibliography.

The English reader is likely to find some difficulties with the terminology, which is often at variance with common usage, and he may well consider also that not a few of the generalizations are still rather speculative and lack compelling evidence. Nevertheless the field studies upon which the argument is chiefly based are intensely interesting, and many of them are highly original. The volume is by far the most important contribution to its topic that has appeared in the English language for a very long time.

F. C. BARTLETT



# Some books received

(Note. Mention of a book on this page does not preclude subsequent review.)

## AGRICULTURE

The Cyst-forming Species of Heterodera, by Mary T. Franklin. Pp. 147, with several half-tone and line illustrations. Commonwealth Agricultural Bureau, Farnham Royal, Bucks. 1951. 18s. 6d. net.

Some Crop Protection Problems in World Agriculture: International Conference. Pp. 116. Plant Protection Limited, London. 1952. 18s. net.

## ASTRONOMY

Radio Astronomy, by Bernard Lovell and J. A. Clegg. Pp. 238, with many half-tone and line illustrations. Chapman and Hall Limited, London. 1952. 16s. net.

## BIOLOGY

Gli Ormoni, by Edgardo Pace. Pp. 543, with several line and half-tone illustrations. Ulrico Hoepli, Milan. 1952. 3500 lire net.

Grundriss der Mikrobiologie, by August Rippel-Baldes. Pp. 404, with many line drawings and half-tone illustrations. Springer-Verlag, Berlin. 1952. DM 36 net.

Human Blood Groups and Inheritance, by Sylvia D. Lawler and L. J. Lawler. Pp. 85. William Heinemann Limited, London. 1952. 3s. 6d. net.

Parasitism and Symbiosis, by Maurice Caullery. Pp. 340, with several line diagrams. Sidgwick and Jackson Limited, London. 1952. 35s. net.

The Use of Trace Elements in Biology, by W. G. Overend. Pp. 57. William Heinemann Limited, London. 1952. 3s. 6d. net.

## BOTANY

The Genetics of Plants, by M. B. Crane and W. J. C. Lawrence. Pp. 301, with various half-tone and line illustrations. Macmillan and Company Limited, London. 1952. 20s. net.

Kulturtechnische Botanik, by Fritz Jürgen Meyer. Pp. 264. Naturwissenschaftlicher Verlag, Berlin. 1951. DM 9 net.

## CHEMISTRY

Light Hydrocarbon Analysis, edited by O. W. Burke, Jr., C. E. Starr, Jr., and F. D. Tuemmler. Pp. 639. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1951. 120s. net.

Progress in Organic Chemistry, I, edited by J. W. Cook. Pp. 287. Butterworths Scientific Publications, London. 1952. 50s. net.

Table of Dielectric Constants of Pure Liquids, by Arthur A. Maryott and Edgar R. Smith. Pp. 44. National Bureau of Standards, Washington. 1951. 30 cents net.

Ultraviolet Spectra of Aromatic Compounds, by Robert A. Friedel and Milton Orchin. Pp. 52, with a collection of 579 spectra diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1952. 80s. net.

## ENGINEERING

Elettrotecnica, by Enrico Astuni. Pp. 273, with many half-tone and line illustrations. Tumminelli, Rome. 1951. 2500 lire net.

Foundations of High Speed Aerodynamics. Facsimiles of nineteen fundamental studies as they were originally reported in the scientific journals. With a bibliography compiled by George F. Carrier. Pp. 286. Dover Publications Inc., New York. 1952. \$1.75 net.

## GENERAL SCIENCE

Atlas de Préhistoire (Vol. I), by H. Alimen. Pp. 205, with many half-tone, colour, and line illustrations. Editions N. Boubée et Cie., Paris. 1950. 900 fr. net.

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## ENDEAVOUR

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The British quarterly scientific review ENDEAVOUR was first published in January 1942. Its purpose was to enable men of science, and particularly British men of science, to speak to the world in an hour when not only nations but the internationalism of science suffered the dangers of warfare. For the better fulfilment of this purpose ENDEAVOUR was from the first published in four separate editions—English, French, Spanish, and German. An Italian edition has been published since January 1948. Today the situation is happily different, but there can be no lasting peace without full and sincere co-operation between nations in every realm of human enterprise. In the scientific field ENDEAVOUR can thus play as useful a part in peace as it did in war, and for this reason the decision has been taken to make its publication permanent.

ENDEAVOUR is distributed without charge to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.



